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Risks to Health and Well-Being From Radio-Frequency Radiation Emitted by Cell Phones and Other Wireless Devices

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Radiation exposure has long been a concern for the public, policy makers, and health researchers. Beginning with radar during World War II, human exposure to radio-frequency radiation[1] (RFR) technologies has grown substantially over time. In 2011, the *International Agency for Research on Cancer* (IARC) reviewed the published literature and categorized RFR as a "possible" (Group 2B) human carcinogen. A broad range of adverse human health effects associated with RFR have been reported since the IARC review. In addition, three large-scale carcinogenicity studies in rodents exposed to levels of RFR that mimic lifetime human exposures have shown significantly increased rates of Schwannomas and malignant gliomas, as well as chromosomal DNA damage. Of particular concern are the effects of RFR exposure on the developing brain in children. Compared with an adult male, a cell phone held against the head of a child exposes deeper brain structures to greater radiation doses per unit volume, and the young, thin skull's bone marrow absorbs a roughly 10-fold higher local dose. Experimental and observational studies also suggest that men who keep cell phones in their trouser pockets have significantly lower sperm counts and significantly impaired sperm motility and morphology, including mitochondrial DNA damage. Based on the accumulated evidence, we recommend that IARC re-evaluate its 2011 classification of the human carcinogenicity of RFR, and that WHO complete a systematic review of multiple other health effects such as sperm damage. In the interim, current knowledge provides justification for governments, public health authorities, and physicians/allied health professionals to warn the population that having a cell phone next to the body is harmful, and to support measures to reduce all exposures to RFR.

Keywords: brain cancer, electromagnetic hypersensitivity, glioma, non-cancer outcomes, policy recommendations, radiofrequency fields, child development, acoustic neuroma

[1] Per IEEE C95.1-1991, the radio-frequency radiation frequency range is from 3 kHz to 300 GHz and is non-ionizing.

INTRODUCTION

We live in a generation that relies heavily on technology. Whether for personal use or work, wireless devices, such as cell phones, are commonly used around the world, and exposure to radiofrequency radiation (RFR) is widespread, including in public spaces (1, 2).

In this review, we address the current scientific evidence on health risks from exposure to RFR, which is in the non-ionizing frequency range. We focus here on human health effects, but also note evidence that RFR can cause physiological and/or morphological effects on bees, plants and trees (3–5).

We recognize a diversity of opinions on the potential adverse effects of RFR exposure from cell or mobile phones and other wireless transmitting devices (WTDs) including cordless phones and Wi-Fi. The paradigmatic approach in cancer epidemiology, which considers the body of epidemiological, toxicological, and mechanistic/cellular evidence when assessing causality, is applied.

CARCINOGENICITY

Since 1998, the *International Commission on Non-Ionizing Radiation Protection* (ICNIRP) has maintained that no evidence of adverse biological effects of RFR exist, other than tissue heating at exposures above prescribed thresholds (6).

In contrast, in 2011, an expert working group of the *International Agency for Research on Cancer* (IARC) categorized RFR emitted by cell phones and other WTDs as a Group 2B ("possible") human carcinogen (7).

Since the IARC categorization, analyses of the large international Interphone study, a series of studies by the Hardell group in Sweden, and the French CERENAT case-control studies, signal increased risks of brain tumors, particularly with ipsilateral use (8). The largest case-control studies on cell phone exposure and glioma and acoustic neuroma demonstrated significantly elevated risks that tended to increase with increasing latency, increasing cumulative duration of use, ipsilateral phone use, and earlier age at first exposure (8).

Pooled analyses by the Hardell group that examined risk of glioma and acoustic neuroma stratified by age at first exposure to cell phones found the highest odds ratios among those first exposed before age 20 years (9–11). For glioma, first use of cell phones before age 20 years resulted in an odds ratio (OR) of 1.8 (95% confidence interval [CI] 1.2–2.8). For ipsilateral use, the OR was 2.3 (CI 1.3-4.2); contralateral use was 1.9 (CI 0.9-3.7). Use of cordless phone before age 20 yielded OR 2.3 (CI 1.4–3.9), ipsilateral OR 3.1 (CI 1.6–6.3) and contralateral use OR 1.5 (CI 0.6–3.8) (9).

Although Karipidis et al. (12) and Nilsson et al. (13) found no evidence of an increased incidence of gliomas in recent years in Australia and Sweden, respectively, Karipidis et al. (12) only reported on brain tumor data for ages 20–59 and Nilsson et al. (13) failed to include data for high grade glioma. In contrast, others have reported evidence that increases in specific types of brain tumors seen in laboratory studies are occurring in Britain and the US:

- The incidence of neuro-epithelial brain cancers has significantly increased in all children, adolescent, and young adult age groupings from birth to 24 years in the United States (14, 15).
- A sustained and statistically significant rise in glioblastoma multiforme across all ages has been described in the UK (16).

The incidence of several brain tumors are increasing at statistically significant rates, according to the 2010–2017 *Central Brain Tumor Registry of the U.S.* (CBTRUS) dataset (17).

- There was a significant increase in incidence of radiographically diagnosed tumors of the pituitary from 2006 to 2012 (APC = 7.3% [95% CI: 4.1%, 10.5%]), with no significant change in incidence from 2012 to 2015 (18).
- Meningioma rates have increased in all age groups from 15 through 85+ years.
- Nerve sheath tumor (Schwannoma) rates have increased in all age groups from age 20 through 84 years.
- Vestibular Schwannoma rates, as a percentage of nerve sheath tumors, have also increased from 58% in 2004 to 95% in 2010-2014.

Epidemiological evidence was subsequently reviewed and incorporated in a meta-analysis by Röösli et al. (19). They concluded that overall, epidemiological evidence does not suggest increased brain or salivary gland tumor risk with mobile phone (MP) use, although the authors admitted that some uncertainty remains regarding long latency periods (>15 years), rare brain tumor subtypes, and MP usage during childhood. Of concern is that these analyses included cohort studies with poor exposure classification (20).

In epidemiological studies, recall bias can play a substantial role in the attenuation of odds ratios toward the null hypothesis. An analysis of data from one large multicenter case-control study of RFR exposure, did not find that recall bias was an issue (21). In another multi-country study it was found that young people can recall phone use moderately well, with recall depending on the amount of phone use and participants' characteristics (22). With less rigorous querying of exposure, prospective cohort studies are unfortunately vulnerable to exposure misclassification and imprecision in identifying risk from rare events, to the point that negative results from such studies are misleading (8, 23).

Another example of disparate results from studies of different design focuses on prognosis for patients with gliomas, depending upon cell phone use. A Swedish study on glioma found lower survival in patients with glioblastoma associated with long term use of wireless phones (24). Ollson et al. (25), however, reported no indication of reduced survival among glioblastoma patients in Denmark, Finland and Sweden with a history of mobile phone use (ever regular use, time since start of regular use, cumulative call time overall or in the last 12 months) relative to no or non-regular use. Notably, Olsson et al. (25) differed from Carlberg and Hardell (24) in that the study did not include use of cordless phones, used shorter latency time and excluded patients older than 69 years. Furthermore, a major shortcoming was that patients with the worst prognosis were excluded, as in Finland

inoperable cases were excluded, all of which would bias the risk estimate toward unity.

In the interim, three large-scale toxicological (animal carcinogenicity) studies support the human evidence, as do modeling, cellular and DNA studies identifying vulnerable subgroups of the population.

The *U.S. National Toxicology Program* (NTP) (National Toxicology Program (26, 27) has reported significantly increased incidence of glioma and malignant Schwannoma (mostly on the nerves on the heart, but also additional organs) in large animal carcinogenicity studies with exposure to levels of RFR that did not significantly heat tissue. Multiple organs (e.g., brain, heart) also had evidence of DNA damage. Although these findings have been dismissed by the ICNIRP (28), one of the key originators of the NTP study has refuted the criticisms (29).

A study by Italy's Ramazzini Institute has evaluated lifespan environmental exposure of rodents to RFR, as generated by 1.8 GHz GSM antennae of cell phone radio base stations. Although the exposures were 60 to 6,000 times lower than those in the NTP study, statistically significant increases in Schwannomas of the heart in male rodents exposed to the highest dose, and Schwann-cell hyperplasia in the heart in male and female rodents were observed (30). A non-statistically significant increase in malignant glial tumors in female rodents also was detected. These findings with far field exposure to RFR are consistent with and reinforce the results of the NTP study on near field exposure. Both reported an increase in the incidence of tumors of the brain and heart in RFR-exposed Sprague-Dawley rats, which are tumors of the same histological type as those observed in some epidemiological studies on cell phone users.

Further, in a 2015 animal carcinogenicity study, tumor promotion by exposure of mice to RFR at levels below exposure limits for humans was demonstrated (31). Co-carcinogenicity of RFR was also demonstrated by Soffritti and Giuliani (32) who examined both power-line frequency magnetic fields as well as 1.8 GHz modulated RFR. They found that exposure to Sinusoidal-50 Hz Magnetic Field (S-50 Hz MF) combined with acute exposure to gamma radiation or to chronic administration of formaldehyde in drinking water induced a significantly increased incidence of malignant tumors in male and female Sprague Dawley rats. In the same report, preliminary results indicate higher incidence of malignant Schwannoma of the heart after exposure to RFR in male rats. Given the ubiquity of many of these co-carcinogens, this provides further evidence to support the recommendation to reduce the public's exposure to RFR to as low as is reasonably achievable.

Finally, a case series highlights potential cancer risk from cell phones carried close to the body. West et al. (33) reported four "extraordinary" multifocal breast cancers that arose directly under the antennae of the cell phones habitually carried within the bra, on the sternal side of the breast (the opposite of the norm). We note that case reports can point to major unrecognized hazards and avenues for further investigation, although they do not usually provide direct causal evidence.

In a study of four groups of men, of which one group did not use mobile phones, it was found that DNA damage indicators in hair follicle cells in the ear canal were higher in the RFR exposure groups than in the control subjects. In addition, DNA damage increased with the daily duration of exposure (34).

Many profess that RFR cannot be carcinogenic as it has insufficient energy to cause direct DNA damage. In a review, Vijayalaxmi and Prihoda (35) found some studies suggested significantly increased damage in cells exposed to RF energy compared to unexposed and/or sham-exposed control cells, others did not. Unfortunately, however, in grading the evidence, these authors failed to consider baseline DNA status or the fact that genotoxicity has been poorly predicted using tissue culture studies (36). As well funding, a strong source of bias in this field of enquiry, was not considered (37).

CHILDREN AND REPRODUCTION

As a result of rapid growth rates and the greater vulnerability of developing nervous systems, the long-term risks to children from RFR exposure from cell phones and other WTDs are expected to be greater than those to adults (38). By analogy with other carcinogens, longer opportunities for exposure due to earlier use of cell phones and other WTDs could be associated with greater cancer risks in later life.

Modeling of energy absorption can be an indicator of potential exposure to RFR. A study modeling the exposure of children 3–14 years of age to RFR has indicated that a cell phone held against the head of a child exposes deeper brain structures to roughly double the radiation doses (including fluctuating electrical and magnetic fields) per unit volume than in adults, and also that the marrow in the young, thin skull absorbs a roughly 10-fold higher local dose than in the skull of an adult male (39). Thus, pediatric populations are among the most vulnerable to RFR exposure.

The increasing use of cell phones in children, which can be regarded as a form of addictive behavior (40), has been shown to be associated with emotional and behavioral disorders. Divan et al. (41) studied 13,000 mothers and children and found that prenatal exposure to cell phones was associated with behavioral problems and hyperactivity in children. A subsequent Danish study of 24,499 children found a 23% increased odds of emotional and behavioral difficulties at age 11 years among children whose mothers reported any cell phone use at age 7 years, compared to children whose mothers reported no use at age 7 years (42). A cross-sectional study of 4,524 US children aged 8–11 years from 20 study sites indicated that shorter screen time and longer sleep periods independently improved child cognition, with maximum benefits achieved with low screen time and age-appropriate sleep times (43). Similarly, a cohort study of Swiss adolescents suggested a potential adverse effect of RFR on cognitive functions that involve brain regions mostly exposed during mobile phone use (44). Sage and Burgio et al. (45) posit that epigenetic drivers and DNA damage underlie adverse effects of wireless devices on childhood development.

RFR exposure occurs in the context of other exposures, both beneficial (e.g., nutrition) and adverse (e.g., toxicants or stress). Two studies identified that RFR potentiated adverse effects of lead on neurodevelopment, with higher maternal use of mobile phones during pregnancy [1,198 mother-child pairs, (46)] and

Attention Deficit Hyper-activity Disorder (ADHD) with higher cell phone use and higher blood lead levels, in 2,422 elementary school children (47).

A study of Mobile Phone Base Station Tower settings adjacent to school buildings has found that high exposure of male students to RFR from these towers was associated with delayed fine and gross motor skills, spatial working memory, and attention in adolescent students, compared with students who were exposed to low RFR (48). A recent prospective cohort study showed a potential adverse effect of RFR brain dose on adolescents' cognitive functions including spatial memory that involve brain regions exposed during cell phone use (44).

In a review, Pall (49) concluded that various non-thermal microwave EMF exposures produce diverse neuropsychiatric effects. Both animal research (50–52) and human studies of brain imaging research (53–56) indicate potential roles of RFR in these outcomes.

Male fertility has been addressed in cross-sectional studies in men. Associations between keeping cell phones in trouser pockets and lower sperm quantity and quality have been reported (57). Both *in vivo* and *in vitro* studies with human sperm confirm adverse effects of RFR on the testicular proteome and other indicators of male reproductive health (57, 58), including infertility (59). Rago et al. (60) found significantly altered sperm DNA fragmentation in subjects who use mobile phones for more than 4 h/day and in particular those who place the device in the trousers pocket. In a cohort study, Zhang et al. (61) found that cell phone use may negatively affect sperm quality in men by decreasing the semen volume, sperm concentration, or sperm count, thus impairing male fertility. Gautam et al. (62) studied the effect of 3G (1.8–2.5 GHz) mobile phone radiation on the reproductive system of male Wistar rats. They found that exposure to mobile phone radiation induces oxidative stress in the rats which may lead to alteration in sperm parameters affecting their fertility.

RELATED OBSERVATIONS, IMPLICATIONS AND STRENGTHS OF CURRENT EVIDENCE

An extensive review of numerous published studies confirms non-thermally induced biological effects or damage (e.g., oxidative stress, damaged DNA, gene and protein expression, breakdown of the blood-brain barrier) from exposure to RFR (63), as well as adverse (chronic) health effects from long-term exposure (64). Biological effects of typical population exposures to RFR are largely attributed to fluctuating electrical and magnetic fields (65–67).

Indeed, an increasing number of people have developed constellations of symptoms attributed to exposure to RFR (e.g., headaches, fatigue, appetite loss, insomnia), a syndrome termed *Microwave Sickness* or *Electro-Hyper-Sensitivity* (EHS) (68–70).

Causal inference is supported by consistency between epidemiological studies of the effects of RFR on induction of human cancer, especially glioma and vestibular Schwannomas, and evidence from animal studies (8). The combined weight of the evidence linking RFR to public health risks includes a broad array of findings: experimental biological evidence of non-thermal effects of RFR; concordance of evidence regarding carcinogenicity of RFR; human evidence of male reproductive damage; human and animal evidence of developmental harms; and limited human and animal evidence of potentiation of effects from chemical toxicants. Thus, diverse, independent evidence of a potentially troubling and escalating problem warrants policy intervention.

CHALLENGES TO RESEARCH, FROM RAPID TECHNOLOGICAL ADVANCES

Advances in RFR-related technologies have been and continue to be rapid. Changes in carrier frequencies and the growing complexity of modulation technologies can quickly render "yesterdays" technologies obsolete. This rapid obsolescence restricts the amount of data on human RFR exposure to particular frequencies, modulations and related health outcomes that can be collected during the lifespan of the technology in question.

Epidemiological studies with adequate statistical power must be based upon large numbers of participants with sufficient latency and intensity of exposure to specific technologies. Therefore, a lack of epidemiological evidence does not necessarily indicate an absence of effect, but rather an inability to study an exposure for the length of time necessary, with an adequate sample size and unexposed comparators, to draw clear conclusions. For example, no case-control study has been published on fourth generation (4G; 2–8 GHz) Long-term Evolution (LTE) modulation, even though the modulation was introduced in 2010 and achieved a 39% market share worldwide by 2018 (71).

With this absence of human evidence, governments must require large-scale animal studies (or other appropriate studies of indicators of carcinogenicity and other adverse health effects) to determine whether the newest modulation technologies incur risks, prior to release into the marketplace. Governments should also investigate short-term impacts such as insomnia, memory, reaction time, hearing and vision, especially those that can occur in children and adolescents, whose use of wireless devices has grown exponentially within the past few years.

The Telecom industry's fifth generation (5G) wireless service will require the placement of many times more small antennae/cell towers close to all recipients of the service, because solid structures, rain and foliage block the associated millimeter wave RFR (72). Frequency bands for 5G are separated into two different frequency ranges. Frequency Range 1 (FR1) includes sub-6 GHz frequency bands, some of which are bands traditionally used by previous standards, but has been extended to cover potential new spectrum offerings from 410 to 7,125 MHz. Frequency Range 2 (FR2) includes higher frequency bands from 24.25 to 52.6 GHz. Bands in FR2 are largely of millimeter wave length, these have a shorter range but a higher available bandwidth than bands in the FR1. 5G technology is being developed as it is also being deployed, with large arrays

of directional, steerable, beam-forming antennae, operating at higher power than previous technologies. 5G is not stand-alone—it will operate and interface with other (including 3G and 4G) frequencies and modulations to enable diverse devices under continual development for the "internet of things," driverless vehicles and more (72).

Novel 5G technology is being rolled out in several densely populated cities, although potential chronic health or environmental impacts have not been evaluated and are not being followed. Higher frequency (shorter wavelength) radiation associated with 5G does not penetrate the body as deeply as frequencies from older technologies although its effects may be systemic (73, 74). The range and magnitude of potential impacts of 5G technologies are under-researched, although important biological outcomes have been reported with millimeter wavelength exposure. These include oxidative stress and altered gene expression, effects on skin and systemic effects such as on immune function (74). *In vivo* studies reporting resonance with human sweat ducts (73), acceleration of bacterial and viral replication, and other endpoints indicate the potential for novel as well as more commonly recognized biological impacts from this range of frequencies, and highlight the need for research before population-wide continuous exposures.

GAPS IN APPLYING CURRENT EVIDENCE

Current exposure limits are based on an assumption that the only adverse health effect from RFR is heating from short-term (acute), time-averaged exposures (75). Unfortunately, in some countries, notably the US, scientific evidence of the potential hazards of RFR has been largely dismissed (76). Findings of carcinogenicity, infertility and cell damage occurring at daily exposure levels—within current limits—indicate that existing exposure standards are not sufficiently protective of public health. Evidence of carcinogenicity alone, such as that from the NTP study, should be sufficient to recognize that current exposure limits are inadequate.

Public health authorities in many jurisdictions have not yet incorporated the latest science from the U.S. NTP or other groups. Many cite 28-year old guidelines by the *Institute of Electrical and Electronic Engineers* which claimed that "Research on the effects of chronic exposure and speculations on the biological significance of non-thermal interactions have not yet resulted in any meaningful basis for alteration of the standard" (77)[2].

Conversely, some authorities have taken specific actions to reduce exposure to their citizens (78), including testing and recalling phones that exceed current exposure limits.

While we do not know how risks to individuals from using cell phones may be offset by the benefits to public health of being able to summon timely health, fire and police emergency services, the findings reported above underscore the importance of evaluating potential adverse health effects from RFR exposure, and taking pragmatic, practical actions to minimize exposure.

We propose the following considerations to address gaps in the current body of evidence:

- As many claim that we should by now be seeing an increase in the incidence of brain tumors if RFR causes them, ignoring the increases in brain tumors summarized above, a detailed evaluation of age-specific, location-specific trends in the incidence of gliomas in many countries is warranted.
- Studies should be designed to yield the strongest evidence, most efficiently:
  - ➢ Population-based case-control designs can be more statistically powerful to determine relationships with rare outcomes such as glioma, than cohort studies. Such studies should explore the relationship between energy absorption (SAR[3]), duration of exposure, and adverse outcomes, especially brain cancer, cardiomyopathies and abnormal cardiac rythms, hematologic malignancies, thyroid cancer.
  - ➢ Cohort studies are inefficient in the study of rare outcomes with long latencies, such as glioma, because of cost-considerations relating to the follow-up required of very large cohorts needed for the study of rare outcomes. In addition, without continual resource-consuming follow-up at frequent intervals, it is not possible to ascertain ongoing information about changing technologies, uses (e.g., phoning vs. texting or accessing the Internet) and/or exposures.
  - ➢ Cross-sectional studies comparing high-, medium-, and low-exposure persons may yield hypothesis-generating information about a range of outcomes relating to memory, vision, hearing, reaction-time, pain, fertility, and sleep patterns.
- Exposure assessment is poor in this field, with very little fine-grained detail as to frequencies and modulations, doses and dose rates, and peak exposures, particularly over the long-term. Solutions such as wearable meters and phone apps have not yet been incorporated in large-scale research.
- Systematic reviews on the topic could use existing databases of research reports, such as the one created by *Oceania Radiofrequency Science Advisory Association* (79) or EMF Portal (80), to facilitate literature searches.
- Studies should be conducted to determine appropriate locations for installation of antennae and other broadcasting systems; these studies should include examination of biomarkers of inflammation, genotoxicity, and other health indicators in persons who live at different radiuses around these installations. This is difficult to study in the general population because many people's greatest exposure arises from their personal devices.
- Further work should be undertaken to determine the distance that wireless technology antennae should be kept away from humans to ensure acceptable levels of safety, distinguishing among a broad range of sources (e.g., from commercial transmitters to Bluetooth devices), recognizing that exposures fall with the inverse of the square of the distance

[2]The FCC adopted the IEEE C95.1 1991 standard in 1996.

[3]When necessary, SAR values should be adjusted for age of child in W/kg.

(The inverse-square law specifies that intensity is inversely proportional to the square of the distance from the source of radiation). The effective radiated power from cell towers needs to be regularly measured and monitored.

POLICY RECOMMENDATIONS BASED ON THE EVIDENCE TO DATE

At the time of writing, a total of 32 countries or governmental bodies within these countries[4] have issued policies and health recommendations concerning exposure to RFR (78). Three U.S. states have issued advisories to limit exposure to RFR (81–83) and the *Worcester Massachusetts Public Schools* (84) voted to post precautionary guidelines on Wi-Fi radiation on its website. In France, Wi-Fi has been removed from pre-schools and ordered to be shut off in elementary schools when not in use, and children aged 16 years or under are banned from bringing cell phones to school (85). Because the national test agency found 9 out of 10 phones exceeded permissible radiation limits, France is also recalling several million phones.

We therefore recommend the following:

1. Governmental and institutional support of data collection and analysis to monitor potential links between RFR associated with wireless technology and cancers, sperm, the heart, the nervous system, sleep, vision and hearing, and effects on children.
2. Further dissemination of information regarding potential health risk information that is in wireless devices and manuals is necessary to respect users' *Right To Know*. Cautionary statements and protective measures should be posted on packaging and at points of sale. Governments should follow the practice of France, Israel and Belgium and mandate labeling, as for tobacco and alcohol.
3. Regulations should require that any WTD that could be used or carried directly against the skin (e.g., a cell phone) or in close proximity (e.g., a device being used on the lap of a small child) be tested appropriately as used, and that this information be prominently displayed at point of sale, on packaging, and both on the exterior and within the device.
4. IARC should convene a new working group to update the categorization of RFR, including current scientific findings that highlight, in particular, risks to youngsters of subsequent cancers. We note that an IARC Advisory Group has recently recommended that RFR should be re-evaluated by the IARC Monographs program with high priority.
5. The World Health Organization (WHO) should complete its long-standing RFR systematic review project, using strong modern scientific methods. National and regional public health authorities similarly need to update their understanding and to provide adequate precautionary guidance for the public to minimize potential health risks.
6. Emerging human evidence is confirming animal evidence of developmental problems with RFR exposure during pregnancy. RFR sources should be avoided and distanced from expectant mothers, as recommended by physicians and scientists (babysafeproject.org).
7. Other countries should follow France, limiting RFR exposure in children under 16 years of age.
8. Cell towers should be distanced from homes, daycare centers, schools, and places frequented by pregnant women, men who wish to father healthy children, and the young.

Specific examples of how the health policy recommendations above, invoking the Precautionary Principle, might be practically applied to protect public health, are provided in the **Annex**.

[4]Argentina, Australia, Austria, Belgium, Canada, Chile, Cyprus, Denmark, European Environmental Agency, European Parliament, Finland, France, French Polynesia, Germany, Greece, Italy, India, Ireland, Israel, Namibia, New Zealand, Poland, Romania, Russia, Singapore, Spain, Switzerland, Taiwan, Tanzania, Turkey, United Kingdom, United States.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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REFERENCES

1. Carlberg M, Hedendahl L, Koppel T, Hardell L. High ambient radiofrequency radiation in Stockholm city, Sweden. *Oncol Lett.* (2019) 17:1777–83. doi: 10.3892/ol.2018.9789
2. Hardell L, Carlberg M, Hedendahl LK. Radiofrequency radiation from nearby base stations gives high levels in an apartment in Stockholm, Sweden: a case report. *Oncol Lett.* (2018) 15:7871–83. doi: 10.3892/ol.2018.8285
3. Halgamuge MN. Review: weak radiofrequency radiation exposure from mobile phone radiation on plants. *Electromagn Biol Med.* (2017) 36:213–35. doi: 10.1080/15368378.2016.1220389
4. Odemer R, Odemer F. Effects of radiofrequency electromagnetic radiation (RF-EMF) on honey bee queen development and mating success. *Sci Total Environ.* (2019) 661:553–62. doi: 10.1016/j.scitotenv.2019.01.154
5. Waldmann-Selsam C, Balmori-de la Plante A, Breunig H, Balmori A. Radiofrequency radiation injures trees around mobile phone base stations. *Sci Total Environ.* (2016) 572:554–69. doi: 10.1016/j.scitotenv.2016.08.045

6. ICNIRP. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). International commission on non-ionizing radiation protection. *Health Phys.* (1998) 74:494–522.
7. IARC. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Non-ionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields*. Lyon: International Agency for Research on Cancer (2013). p. 102.
8. Miller AB, Morgan LL, Udasin I, Davis DL. Cancer epidemiology update, following the 2011 IARC evaluation of radiofrequency electromagnetic fields (Monograph 102). *Environ Res.* (2018) 167:673–83. doi: 10.1016/j.envres.2018.06.043
9. Hardell L, Carlberg M. Mobile phone and cordless phone use and the risk for glioma - analysis of pooled case-control studies in Sweden, 1997-2003 and 2007-2009. *Pathophysiology.* (2015) 22:1–13. doi: 10.1016/j.pathophys.2014.10.001
10. Hardell L, Carlberg M, Söderqvist F, Kjell HM. Pooled analysis of case-control studies on acoustic neuroma diagnosed 1997-2003 and 2007-2009 and use of mobile and cordless phones. *Int J Oncol.* (2013) 43:1036–44. doi: 10.3892/ijo.2013.2025
11. Hardell L, Carlberg M, Gee D. Chapter 21: Mobile phone use and brain tumour risk: early warnings, early actions? In: *Late Lessons From Early Warnings, Part 2. European Environment Agency, Copenhagen.* Denmark (2013). Available online at: https://www.eea.europa.eu/publications/late-lessons-2/late-lessons-chapters/late-lessons-ii-chapter-21/view (accessed August 25, 2018)
12. Karipidis K, Elwood M, Benke G, Sanagou M, Tjong L, Croft RJ. Mobile phone use and incidence of brain tumour histological types, grading or anatomical location: a population-based ecological study. *BMJ Open.* (2018) 8:e024489. doi: 10.1136/bmjopen-2018-024489
13. Nilsson J, Järås J, Henriksson R, Holgersson G, Bergström S, Estenberg J. No evidence for increased brain tumour incidence in the Swedish national cancer register between years 1980-2012. *Anticancer Res.* (2019) 39:791–6. doi: 10.21873/anticanres.13176
14. Gittleman HR, Ostrom QT, Rouse CD, Dowling JA, de Blank PM, Kruchko CA, et al. Trends in central nervous system tumor incidence relative to other common cancers in adults, adolescents, and children in the United States, 2000 to 2010. *Cancer*. (2015) 121:102–12. doi: 10.1002/cncr.29015
15. Ostrom QT, Gittleman H, de Blank PM, Finlay JL, Gurney JG, McKean-Cowdin R, et al. Adolescent and young adult primary brain and central nervous system tumors diagnosed in the United States in 2008-2012. *Neuro-Oncology*. (2016) 18 (suppl. 1):1–50. doi: 10.1093/neuonc/nov297
16. Philips A, Henshaw DL, Lamburn G, O'Carroll MJ. Brain tumours: rise in glioblastoma multiforme incidence in England 1995–2015 suggests an adverse environmental or lifestyle factor. *J Public Health Environ.* (2018) 2018:7910754. doi: 10.1155/2018/2170208
17. Central Brain Tumor Registry of the United States. *Primary Brain and Other Central Nervous System Tumors Diagnosed in the United States*. Annual Reports. 2007–2017. (2017)
18. Ostrom QT, Gittleman H, Truitt G, Boscia A, Kruchko C, Barnholtz-Sloan JS. CBTRUS statistical report: primary brain and other central nervous system tumors diagnosed in the United States in 2011–2015. *Neuro-Oncology*. (2018) 20:1–86. doi: 10.1093/neuonc/noy131
19. Röösli M, Lagorio S, Schoemaker MJ, Schüz J, Feychting M. Brain and salivary gland tumors and mobile phone use: evaluating the evidence from various epidemiological study designs. *Annu Rev Public Health.* (2019) 40:221–38. doi: 10.1146/annurev-publhealth-040218-044037
20. Söderqvist F, Carlberg M, Hardell L. Review of four publications on the Danish cohort study on mobile phone subscribers and risk of brain tumours. *Rev Environ Health.* (2012) 27:51–8. doi: 10.1515/reveh-2012-0004
21. Vrijheid M, Deltour I, Krewski D, Sanchez M, Cardis E. The effects of recall errors and of selection bias in epidemiologic studies of mobile phone use and cancer risk. *J Expo Sci Environ Epidemiol.* (2006) 16:371–84. doi: 10.1038/sj.jes.7500509
22. Goedhart G, van Wel L, Langer CE, de Llobet Viladoms P, Wiart J, Hours M, et al. Recall of mobile phone usage and laterality in young people: the multinational Mobi-Expo study. *Environ Res.* (2018) 165:150–7. doi: 10.1016/j.envres.2018.04.018
23. Brzozek C, Benke KK, Zeleke BM, Abramson MJ, Benke G. Radiofrequency electromagnetic radiation and memory performance: sources of uncertainty in epidemiological cohort studies. *Int J Environ Res Public Health.* (2018) 15:E592. doi: 10.3390/ijerph15040592
24. Carlberg M, Hardell L. Decreased survival of glioma patients with astrocytoma grade IV (glioblastoma multiforme) associated with long-term use of mobile and cordless phones. *Int J Environ Res Public Health.* (2014) 11:10790–805. doi: 10.3390/ijerph111010790
25. Olsson A, Bouaoun L, Auvinen A, Feychting M, Johansen C, Mathiesen T, et al. Survival of glioma patients in relation to mobile phone use in Denmark, Finland and Sweden. *J Neurooncol.* (2019) 141:139–49. doi: 10.1007/s11060-018-03019-5
26. National Toxicology Program. *NTP Technical Report on the Toxicology and Carcinogenesis Studies in Hsd:Sprague-Dawley SD Rats Exposed to Whole-Body Radio Frequency Radiation at a Frequency (900 MHz) and Modulations (GSM and CDMA) Used by Cell Phones*. NTP TR 595. (2018). Available online at: https://ntp.niehs.nih.gov/ntp/about_ntp/trpanel/2018/march/tr595peerdraft.pdf (accessed August 25, 2018).
27. National Toxicology Program. *NTP Technical Report on the Toxicology and Carcinogenesis Studies in B6C3F1/N Mice Exposed to Whole-Body Radio Frequency Radiation at a Frequency (1800 MHz) and Modulations (GSM and CDMA) Used by Cell Phones*. NTP TR 596. (2018). Available online at: https://ntp.niehs.nih.gov/ntp/about_ntp/trpanel/2018/march/tr596peerdraft.pdf (accessed August 25, 2018).
28. ICNIRP. *ICNIRP Note on Recent Animal Carcinogenesis Studies*. Munich (2018). Available online at: https://www.icnirp.org/cms/upload/publications/ICNIRPnote2018.pdf (accessed September 29, 2018).
29. Melnick RL. Commentary on the utility of the National Toxicology Program study on cellphone radiofrequency radiation data for assessing human health risks despite unfounded criticisms aimed at minimizing the findings of adverse health effects. *Environ Res.* (2019) 168:1–6. doi: 10.1016/j.envres.2018.09.010
30. Falcioni L, Bua L, Tibaldi E, Lauriola M, De Angelis L, Gnudi F, et al. Report of final results regarding brain and heart tumors in Sprague-Dawley rats exposed from prenatal life until natural death to mobile phone radiofrequency field representative of a 1.8 GHz GSM base station environmental emission. *Environ Res.* (2018) 165:496–503. doi: 10.1016/j.envres.2018.01.037
31. Lerchl A, Klose M, Grote K, Wilhelm AF, Spathmann O, Fiedler T, et al. Tumor promotion by exposure to radiofrequency electromagnetic fields below exposure limits for humans. *Biochem Biophys Res Commun.* (2015) 459:585–90. doi: 10.1016/j.bbrc.2015.02.151
32. Soffritti M, Giuliani L. The carcinogenic potential of non-ionizing radiations: the cases of S-50 Hz MF, and 1.8 GHz GSM radiofrequency radiation. *Basic Clin Pharmacol Toxicol.* (2019). doi: 10.1111/bcpt.13215
33. West JG, Kapoor NS, Liao SY, Chen JW, Bailey L, Nagourney RA. Multifocal breast cancer in young women with prolonged contact between their breasts and their cellular phones. *Case Rep Med.* (2013) 2013:354682. doi: 10.1155/2013/354682
34. Akdag M, Dasdag S, Canturk F, Akdag MZ. Exposure to non-ionizing electromagnetic fields emitted from mobile phones induced DNA damage in human ear canal hair follicle cells. *Electromagn Biol Med.* (2018) 37:66–75. doi: 10.1080/15368378.2018.1463246
35. Vijayalaxmi, Prihoda TJ. Comprehensive review of quality of publications and meta-analysis of genetic damage in mammalian cells exposed to non-ionizing radiofrequency fields. *Radiat Res.* (2019) 191:20–30. doi: 10.1667/RR15117.1
36. Corvi R, Madia F. *In vitro* genotoxicity testing–can the performance be enhanced? *Food Chem Toxicol.* (2017) 106:600–8. doi: 10.1016/j.fct.2016.08.024
37. Huss A, Egger M, Hug K, Huwiler-Müntener K, Röösli M. Source of funding and results of studies of health effects of mobile phone use: systematic review of experimental studies. *Environ Health Perspect*. (2007) 115:1–4. doi: 10.1289/ehp.9149
38. Redmayne M, Smith E, Abramson MJ. The relationship between adolescents' well-being and their wireless phone use: a cross-sectional study. *Environ Health.* (2013) 12:90. doi: 10.1186/1476-069X-12-90
39. Fernández C, de Salles AA, Sears ME, Morris RD, Davis DL. Absorption of wireless radiation in the child versus adult brain and eye from cell phone conversation or virtual reality. *Environ Res.* (2018) 167:694–9. doi: 10.1016/j.envres.2018.05.013

40. De-Sola Gutiérrez J, Rodríguez de Fonseca F, Rubio G. Cell-phone addiction: a review. *Front Psychiatry*. (2016) 7:175. doi: 10.3389/fpsyt.2016.00175
41. Divan HA, Kheifets L, Obel C, Olsen J. Prenatal and postnatal exposure to cell phone use and behavioral problems in children. *Epidemiology*. (2008) 19:523–9. doi: 10.1097/EDE.0b013e318175dd47
42. Sudan M, Olsen J, Arah OA, Obel C, Kheifets L. Prospective cohort analysis of cellphone use and emotional and behavioural difficulties in children. *J Epidemiol Community Health*. (2016) 70:1207–13. doi: 10.1136/jech-2016-207419
43. Walsh JJ, Barnes JD, Cameron JD, Goldfield GS, Chaput JP, Gunnell KE, et al. Associations between 24 hour movement behaviours and global cognition in US children: a cross-sectional observational study. *Lancet Child Adolesc Health*. (2018) 2:783–91. doi: 10.1016/S2352-4642(18)30278-5
44. Foerster M, Thielens A, Joseph W, Eeftens M, Röösli M. A prospective cohort study of adolescents' memory performance and individual brain dose of microwave radiation from wireless communication. *Environ Health Perspect*. (2018) 126:077007. doi: 10.1289/EHP2427
45. Sage C, Burgio E. Electromagnetic fields, pulsed radiofrequency radiation, and epigenetics: how wireless technologies may affect childhood development. *Child Dev*. (2018) 89:129–36. doi: 10.1111/cdev.12824
46. Choi KH, Ha M, Ha EH, Park H, Kim Y, Hong YC, et al. Neurodevelopment for the first three years following prenatal mobile phone use, radio frequency radiation and lead exposure. *Environ Res*. (2017) 156:810–17. doi: 10.1016/j.envres.2017.04.029
47. Byun YH, Ha M, Kwon HJ, Hong YC, Leem JH, Sakong J, et al. Mobile phone use, blood lead levels, and attention deficit hyperactivity symptoms in children: a longitudinal study. *PLoS ONE*. (2013) 8:e59742. doi: 10.1371/journal.pone.0059742
48. Meo SA, Almahmoud M, Alsultan Q, Alotaibi N, Alnajashi I, Hajjar WM. Mobile phone base station tower settings adjacent to school buildings: impact on students' cognitive health. *Am J Mens Health*. (2018) 13:1557988318816914. doi: 10.1177/1557988318816914
49. Pall ML. Microwave frequency electromagnetic fields (EMFs) produce widespread neuropsychiatric effects including depression. *J Chem Neuroanat*. (2016) 75:43–51. doi: 10.1016/j.jchemneu.2015.08.001
50. Deniz OG, Suleyman K, Mustafa BS, Terzi M, Altun G, Yurt KK, et al. Effects of short and long term electromagnetic fields exposure on the human hippocampus. *J Microsc Ultrastruct*. (2017) 5:191–7. doi: 10.1016/j.jmau.2017.07.001
51. Eghlidospour M, Amir G, Seyyed MJM, Hassan A. Effects of radiofrequency exposure emitted from a GSM mobile phone on proliferation, differentiation, and apoptosis of neural stem cells. *Anatomy Cell Biol*. (2017) 50:115–23. doi: 10.5115/acb.2017.50.2.115
52. Aldad TS, Gan G, Gao XB, Taylor HS. Fetal radiofrequency radiation exposure from 800-1900 Mhz-Rated cellular telephones affects neurodevelopment and behavior in mice. *Sci Rep*. (2012) 2:312. doi: 10.1038/srep00312
53. Huber R, Treyer V, Borbély AA, Schuderer J, Gottselig JM, Landolt HP, et al. Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG. *J Sleep Res*. (2002) 11:289–95. doi: 10.1046/j.1365-2869.2002.00314.x
54. Huber R, Treyer V, Schuderer J, Berthold T, Buck A, Kuster N, et al. Exposure to pulse-modulated radio frequency electromagnetic fields affects regional cerebral blood flow. *Eur J Neurosci*. (2005) 21:1000–6. doi: 10.1111/j.1460-9568.2005.03929.x
55. Volkow ND, Tomasi D, Wang GJ, Vaska P, Fowler JS, Telang F, et al. Effects of cell phone radiofrequency signal exposure on brain glucose metabolism. *JAMA*. (2011) 305:808–13. doi: 10.1001/jama.2011.186
56. Kostoff RN, Lau CGY. Combined biological and health effects of electromagnetic fields and other agents in the published literature. *Technol Forecast Soc Change*. (2013) 80:1331–49. doi: 10.1016/j.techfore.2012.12.006
57. Adams JA, Galloway TS, Mondal D, Esteves SC, Mathews F. Effect of mobile telephones on sperm 421 quality: a systematic review and meta-analysis. *Environ Int*. (2014) 70:106–12. doi: 10.1016/j.envint.2014.04.015
58. Houston BJ, Nixon B, King BV, De Iuliis GN, Aitken RJ. The effects of radiofrequency electromagnetic radiation on sperm function. *Reproduction*. (2016) 152:R263–76. doi: 10.1530/REP-16-0126
59. Kesari KK, Agarwal A, Henkel R. Radiations and male fertility. *Reprod Biol Endocrinol*. (2018) 16:118. doi: 10.1186/s12958-018-0431-1
60. Rago R, Salacone P, Caponecchia L, Sebastianelli A, Marcucci I, Calogero AE, et al. The semen quality of the mobile phone users. *J Endocrinol Invest*. (2013) 36:970–4. doi: 10.3275/8996
61. Zhang G, Yan H, Chen Q, Liu K, Ling X, Sun L, et al. Effects of cell phone use on semen parameters: results from the MARHCS cohort study in Chongqing, China. *Environ Int*. (2016) 91:116–21. doi: 10.1016/j.envint.2016.02.028
62. Gautam R, Singh KV, Nirala J, Murmu NN, Meena R, Rajamani P. Oxidative stress-mediated alterations on sperm parameters in male Wistar rats exposed to 3G mobile phone radiation. *Andrologia*. (2019) 51:e13201. doi: 10.1111/and.13201
63. BioInitiative Working Group. *A Rationale for Biologically-Based Exposure Standards for Low-Intensity Electromagnetic Radiation*. BioInitiative. (2012) Available online at: https://www.bioinitiative.org/ (accessed August 25, 2018).
64. Belyaev I. Dependence of non–thermal biological effects of microwaves on physical and biological variables: implications for reproducibility and safety standards. In: Giuliani L, Soffritti M, Editors. *Non–Thermal Effects and Mechanisms of Interaction Between Electromagnetic Fields and Living Matter*, Vol. 5. Bologna: Ramazzini Institute (2010). p. 187–218.
65. Barnes F, Greenebaum B. Some effects of weak magnetic fields on biological systems: RF fields can change radical concentrations and cancer cell growth rates. In: *IEEE Power Electronics Magazine 3, (March*) (2016). p. 60–8.
66. Panagopoulos DJ, Johansson O, Carlo GL. Evaluation of specific absorption rate as a dosimetric quantity for electromagnetic fields bioeffects. *PLoS ONE*. (2013) 8:e62663. doi: 10.1371/journal.pone.0062663
67. Ying L, Héroux P. Extra-low-frequency magnetic fields alter cancer cells through metabolic restriction. *Electromagn Biol Med*. (2013) 33:264–75. doi: 10.3109/15368378.2013.817334
68. Belyaev I, Dean A, Eger H, Hubmann G, Jandrisovits R, Kern M, et al. EUROPAEM EMF guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses. *Rev Environ Health*. (2016) 31:363–97. doi: 10.1515/reveh-2016-0011
69. Heuser G, Heuser SA. Functional brain MRI in patients complaining of electrohypersensitivity after long term exposure to electromagnetic fields. *Rev Environ Health*. (2017) 32:291–9. doi: 10.1515/reveh-2017-0014
70. Belpomme D, Hardell L, Belyaev I, Burgio E, Carpenter DO. Thermal and non-thermal health effects of low intensity non-ionizing radiation: an international perspective. *Environ Pollut*. (2018) 242:643–58. doi: 10.1016/j.envpol.2018.07.019
71. Anonymous. *LTE Achieves 39% Market Share Worldwide*. (2018). Available online at: http://www.microwavejournal.com/articles/30603-lte-achieves (accessed September 29, 2018).
72. Rappaport TS, Sun S, Mayzus R, Zhao H, Azar Y, Wang K, et al. Millimeter wave mobile communications for 5G cellular: it will work! *IEEE Access*. (2013) 1:335–49. doi: 10.1109/ACCESS.2013.2260813
73. Beltzalel N, Ben Ishai P, Feldman Y. The human skin as a sub-THz receiver - Does 5G pose a danger to it or not? *Environ Res*. (2018) 163:208–16. doi: 10.1016/j.envres.2018.01.032
74. Russell CL. 5G wireless telecommunications expansion: public health and environmental implications. *Environ Res*. (2018) 165:484–95. doi: 10.1016/j.envres.2018.01.016
75. Federal Communication Commission. *Radio Frequency Safety 13-39 Section 112*. 37. First Report and Order March 29, 2013 (2013). Available online at: https://apps.fcc.gov/edocs_public/attachmatch/FCC-13-39A1.pdf (accessed August 25, 2018).
76. Alster N. *Captured Agency: How the Federal Communications Commission Is Dominated by the Industries It Presumably Regulates*. Cambridge, MA: Edmond J. Safra Center for Ethics Harvard University (2015).
77. Institute of Electrical and Electronic Engineers. (IEEE)IEEE c95.1 IEEE Standard for Safety Levels with respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHZ to 300 GHz. (1991) Available online at: https://ieeexplore.ieee.org/document/1626482/(accessed August 25, 2018).
78. Environmental Health Trust. *Database of Worldwide Policies on Cell Phones*, Wireless and Health (2018) Available online at: https://ehtrust.org/policy/international-policy-actions-on-wireless/ (accessed August 25, 2018).

79. Leach V, Weller S, Redmayne M. Database of bio-effects from non-ionizing radiation. A novel database of bio-effects from non-ionizing radiation. *Rev Environ Health*. (2018) 33:273–80. doi: 10.1515/reveh-2018-0017
80. *EMF Portal of the RWTH Aachen University*. (2018). Available online at: https://www.emf-portal.org/en (accessed October 10, 2018).
81. CDPH. *CDPH Issues Guidelines on How to Reduce Exposure to Radio Frequency Energy from Cell Phones*. (2017) Available online at: https://www.cdph.ca.gov/Programs/OPA/Pages/NR17-086.aspx (accessed August 25, 2018).
82. Connecticut Department of Public Health. *Cell Phones: Questions and Answers about Safety*. (2017) Available online at: https://portal.ct.gov/-/media/Departments-and-Agencies/DPH/dph/environmental_health/eoha/Toxicology_Risk_Assessment/050815CellPhonesFINALpdf.pdf?la=en (accessed August 25, 2018).
83. Massachusetts, United States of America. Legislative Update on Bills on Wireless and Health. (2017) Available onlilne at: https://ehtrust.org/massachusetts-2017-bills-wireless-health/ (accessed August 25, 2018).
84. *Worcester School Committee Precautionary Option on Radiofrequency Exposure*. (2017). Available online at: http://wpsweb.com/sites/default/files/www/school_safety/radio_frequency.pdf (accessed August 25, 2018).
85. Samuel H. The Telegraph. *France to Impose Total Ban on Mobile Phones in Schools*. (2018). Available online at: https://www.telegraph.co.uk/news/2017/12/11/france-impose-total-ban-mobile-phones-schools/ (accessed August 25, 2018).
86. Moskowitz JM. *Berkeley Cell Phone "Right to Know" Ordinance*. (2014). Available online at: https://ehtrust.org/policy/the-berkeley-cell-phone-right-to-know-ordinance and Available online at: https://www.saferemr.com/2014/11/berkeley-cell-phone-right-to-know.html (accessed September 29, 2018).

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Building science and radiofrequency radiation: What makes smart and healthy buildings

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ABSTRACT

Radiofrequency radiation (RFR), used for wireless communications and "smart" building technologies, including the "Internet of Things," is increasing rapidly. As both RFR exposures and scientific evidence of harmful effects increase apace, it is timely to heed calls to include low RFR levels as a performance indicator for the health, safety and well-being of occupants and the environment.

Adverse biochemical and biological effects at commonly experienced RFR levels indicate that exposure guidelines for the U.S., Canada and other countries are inadequate to protect public health and the environment.

Some industry liability insurance providers do not offer coverage against adverse health effects from radiation emitted by wireless technologies, and insurance authorities deem potential liability as "high." Internationally, governments have enacted laws, and medical and public health authorities have issued recommendations, to reduce and limit exposure to RFR.

There is an urgent need to implement strategies for no- or low-RFR emitting technologies, and shielding, in building design and retrofitting. These strategies include installing wired (not wireless) Internet networks, corded rather than cordless phones, and cable or wired connections in building systems (e.g., mechanical, lighting, security). Building science can profit from decades of work to institute performance parameters, operationalizing prudent guidelines and best practices. The goal is to achieve RFR exposures that are ALARA, "As Low As Reasonably Achievable."

We also challenge the business case of wireless systems, because wired or cabled connections are faster, more reliable and secure, emit substantially less RFR, and consume less energy in a sector with rapidly escalating greenhouse gas emissions.

1. Introduction

Radiofrequency radiation (RFR) exposures are increasing rapidly with wireless technologies, but rarely are the terms "building science" and "RFR" used in the same sentence. Building science attends to the physical performance of buildings, the comfort, health, safety of occupants, and the larger natural and built environment [1]. "Science" includes physics and the electromagnetic spectrum, including RFR.

Building science considers the building *as a system* and devises effective solutions for design concerns. The primary system elements include: the building enclosure (building envelope); inhabitants (humans, animals, and/or plants); building services (electrical/mechanical/

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electronic systems); site, with its landscape and services infrastructure; and external environment (landscape, weather and micro-climate) [1]. To achieve a well-performing building, all these elements must be harmonized.

Historically, awareness of indoor environmental quality heightened with novel materials following World War II, and was bolstered with improved air-tightness during the energy crisis of the 1980s. Minimizing chemical off-gassing of composite materials, maintenance products and mold is advised to optimize indoor air quality and occupants' health [2]. Similarly, magnetic and electrical fields and currents with early electrical applications are also associated with adverse health effects. Assiduous adherence to electrical codes and best practices, and isolation of potentially problematic equipment, are among measures to address ongoing power-frequency, "dirty power" and ground current concerns [3,4].

Today engineers, architects, planners and others are challenged to keep abreast of research and policies that address potential harm from wireless technology. This paper builds on long-standing recommendations to expand the typical scope of building science to consider RFR [3,4]. It briefly describes RFR in the electromagnetic spectrum, use of wireless technology in "smart" buildings, and summarizes peer-reviewed, scientific research regarding biological effects on human and environmental health. Key reasons as to why action should be taken include potential liability risks when technology is not implemented safely. International measures and guidelines for lower RFR exposure are highlighted. Finally, practices are outlined and recommendations made to minimize the impact of RFR on public and environmental health in the design, construction and maintenance of safer, modern buildings.

Internationally, a broad range of standards and policies limit magnetic and electric fields over a broad range of frequencies, including RFR [5]. It is beyond the scope of this paper to address the full electromagnetic spectrum.

2. Radiofrequency radiation explained

2.1. The electromagnetic spectrum

The electromagnetic spectrum (Fig. 1) is a continuum ranging from low to high frequencies, associated with the longest to shortest wavelengths, respectively [6,7]. A distinction is made between high frequency non-ionizing versus higher frequency ionizing radiation that has enough energy to displace electrons and "ionize" atoms and molecules. Ionizing radiation includes ultraviolet light, X-rays and gamma rays. Below these frequencies, non-ionizing radiation includes visible and infrared light, and frequencies for wireless communications and radar. Lower frequencies are used to broadcast commercial radio and television, while alternating currents at 50 or 60 cycles per second or Hertz (Hz) are in power lines and building wiring.

RFR is sent wirelessly from a transceiver (e.g., Wi-Fi router) to another transceiver (e.g., computer) and vice versa. The RFR frequency range covered in guidelines and standards is generally from 3 kHz to 300 GHz and includes the microwave (MW) range. The terms RFR and MW are sometimes used interchangeably. Uses of frequency ranges overlap, so there are no precise boundaries for any particular technology. Information is encoded in the modulation (superimposed higher frequency irregularities) on a radiofrequency carrier wave. While the frequency of the carrier wave is stated in the manufacturer's specifications for various devices, the actual human exposure includes these overlain or superimposed signals [6]. Modern devices utilize multiple carrier frequencies.

Devices that receive and emit RFR include personal items that communicate wirelessly such as: cordless and mobile phones; computers, laptops, tablets and peripheral equipment; monitors (e.g., for babies, or medical purposes); toys, video game and entertainment systems; virtual reality headsets; GPS systems; and Bluetooth-enabled "wearables" such as for personal fitness. RFR-emitting equipment that may be installed in buildings includes: wireless routers and associated mesh networks; "smart" utility metering; identification and security systems; cell boosters; power transfer/battery charging stations; and the "Internet of Things" (IoT) such as building systems (e.g., heating, ventilation and lighting), and appliance monitoring and control.[1] These devices are designed to use a number of presently used plus new radiofrequency bands, from 600 MHz to GHz frequencies. Fifth generation or 5G frequencies that are being licensed by the U.S. Federal Communications Commission (FCC) will include lower frequencies used for television, through higher frequencies into the millimeter wavelength range (above 30 GHz) [9]. Higher frequencies provide greater bandwidth, albeit with shorter range and poorer penetration of structures and vegetation; these are discussed in Section 3.1.

Microwave ovens and other RFR-emitting devices (e.g., Wi-Fi and cell phones) rely on similar frequencies, but the power and signal characteristics are different. Ovens heat with 1000 Watts (W) of continuous-wave radiation, whereas wireless devices are lower power; for example a cell phone is a two-way microwave radio, using on average less than 1 W of modulated radiation. Wireless communications signals, however, are in short bursts, that are biologically active, independent of the carrier frequency [10,11]. Another key feature of anthropogenic electromagnetic radiation is polarization; i.e., that the waves may be in one plane [12].

2.2. Regulatory history of RFR in the United States

In the U.S., the FCC authorizes and licenses devices, transmitters and facilities that generate RFR [13]. The U.S. does not have federally developed safety limits, as the Environmental Protection Agency never developed biologically based limits. The current FCC RFR exposure limits were adopted in 1996 based on recommendations from the National Council on Radiation Protection and Measurements (NCRP) [14], the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers, Inc. (IEEE); specifically *IEEE C95.1–1991* and *ANSI/IEEE C95.1–1992*. None of these institutes have expertise in public health or biology. The FCC RFR exposure guidelines have not been substantially revised since 1996.

Presently, frequency bands between 9 kHz and 275 GHz have been allocated for various communications uses by the FCC [15].

2.3. RFR guidelines

The FCC RFR limits for public exposure reference three metrics: 1) the "Specific Absorption Rate" (SAR) is the rate at which RF energy is absorbed by human tissue; 2) power density, the rate of deposition of energy per unit area, is a function of the electrical and magnetic fields, at a particular frequency; and 3) the electrical field strength [7]. SAR limits apply to wireless wearable devices, cell phones and other items held close to the body. Power density limits apply to exposures at a distance, such as from cellular antennas and Wi-Fi.

2.3.1. Specific Absorption Rate (SAR)

The FCC and other governments' agencies require that all wireless devices such as cell phones or computers comply with SAR limits when the device is operating at its maximum power, before being placed on the market.

SAR is a measure of RFR energy dose to parts of the body closest to antennas, in the "near field," such as from the personal use of wireless devices. SAR is usually expressed in units of Watts per kilogram (W/kg) or milliwatts per gram (mW/g). The SAR for a given power density varies according to equipment details, the frequency and modulation,

[1] IoT is the comprehensive plan to connect billions of physical devices around the world to the Internet, collecting and sharing data.

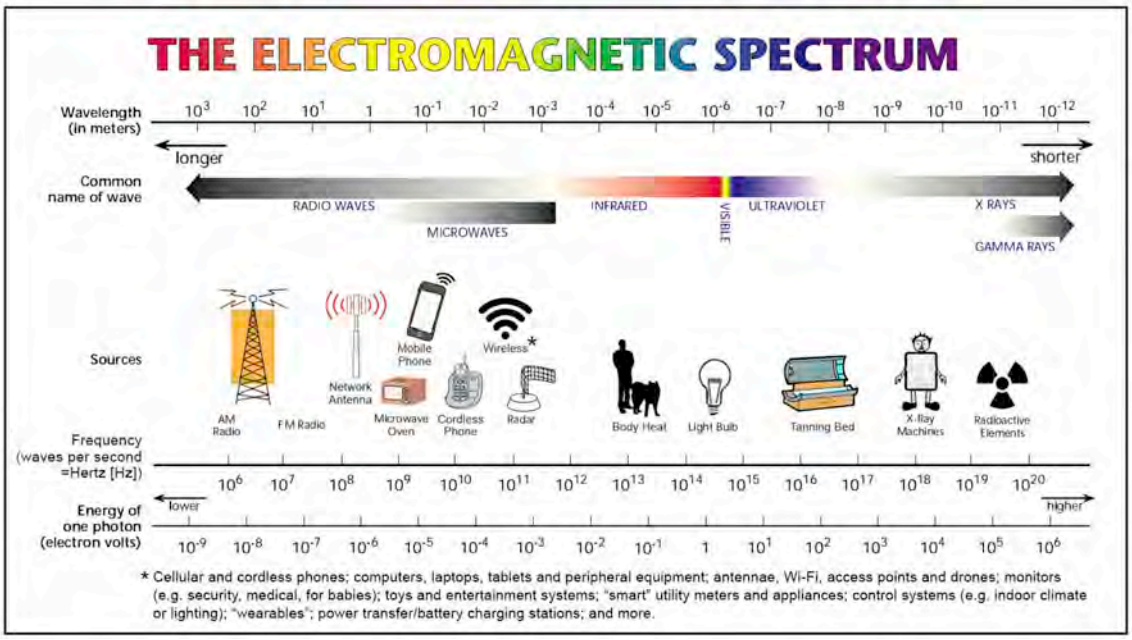

Fig. 1. The Electromagnetic spectrum (presented with permission) [8].

and the absorptive and reflective properties of the body or structure being exposed [7].

The FCC promulgated both public and occupational SAR limits. For the general public (commercial devices), the SAR limits for the head and the body are 1.6 W/kg averaged over a 1 g cube of tissue, and 4 W/kg averaged over a 10 g cube of tissue for ears, hands, feet, wrists and ankles [16]. Workers may be exposed to higher levels; occupational SAR limits are double those for the general public in the U.S., and five-fold greater for workers in "controlled environments" in Canada [17] as well as the many countries relying upon International Commission on Non-ionizing Radiation Protection (ICNIRP) guidelines [18].

Researchers have long criticized the SAR as an inadequate metric as it is measured in a mannequin – a liquid-filled phantom [19]. This does not capture the complex characteristics and interactions of living tissues' electromagnetic properties, or of RFR signals (e.g., the wave perturbations necessary to transmit information may cause additional biological impacts) [20]. FCC SAR limits and the measured SAR levels can be found in the manufacturer's instructions that come with every commercially sold wireless device, or on the manufacturer's website.

SAR testing protocols do not require cell phones and devices to be tested touching the body/skin or in novel configurations such as for virtual reality, despite the fact that this is the way they are often carried and used today [20,21,22]. Some cell phones are tested at as much as 25 mm separation distance. The national agency regulating radio-frequency radiation in France (ANFR) tested 450 cell phones in various configurations. The SAR exceeded the standard for 90% of the models that were tested as if they were contacting the body [23,24]. More than a dozen models were withdrawn from the market or had software updates to reduce RFR emissions.

2.3.2. Power density

Power density measurements address compliance in buildings or outdoor environments, such as when concerns are raised about RFR exposures from a nearby cell tower or from the Wireless Local Area Network (WLAN) system in a school. The FCC exposure limits range from 0.4 to 1.0 mW/cm^2 (4000 to 10,000 mW/m^2) [16] for commonly used frequencies.

Power density may be expressed as milliWatts or microWatts per square centimeter (mW/cm^2 or $\mu W/cm^2$), or milliWatts per square meter (mW/m^2).

For comparison, 1 mW/cm^2 = 1000 $\mu W/cm^2$ = 10,000 mW/m^2.

2.3.3. Electric field

"Electromagnetic" refers to both electrical and magnetic fields (EMF). Limits are established for electric fields, reported as volts per meter (V/m). Electric fields are commonly measured and reported during surveys of radiofrequency exposures, to characterize electromagnetic fields (EMF) across a broad range of frequencies [7].

2.3.4. Exposure attenuation

RFR reductions are generally reported as decibels. This is a non-linear, logarithmic scale, such that a signal that is 10 dB lower than another, is one tenth the signal strength of the comparator [25].

3. Information technologies and building science

Indoor environmental quality (IEQ) in more highly developed countries has advanced in terms of thermal comfort, air quality and construction for environmental performance (e.g., insulation), for example with guidance and classifications by The World Green Building Council [26] or Leadership in Energy and Environmental Design (LEED) [27]. These factors translate into familiar physical sensations of warmth, fresh air and comfort, versus cold drafts and stuffy air. Over the past decades, understanding of the modern sources of lower frequencies and now RFR within and surrounding building assemblies, and effects on inhabitants and surroundings, has gained recognition [3,28].

3.1. Developing technologies

Beyond Wi-Fi, a recent trend is the integration of wireless controls for lighting and heating/ventilation, as well as wireless security and audio/visual technology systems in buildings. "Smart buildings," with "smart systems" and "smart appliances" allow users to monitor and to control many interconnected mechanical and electronic systems via computers or "smart phones." Utility providers are utilizing "smart meters" for electricity, gas and water to transmit usage data electronically using RFR. Wireless charging stations for many items, from electronic devices to vehicles, may be additional sources of EMF.

Plans for the burgeoning IoT and 5th Generation (5G) wireless services are to transport large volumes of data quickly (e.g., for videos).

The proposed evolution of the “smart city” will imbue entire buildings and neighborhoods with higher levels of currently used frequencies, as well as the higher frequencies into millimeter wavelengths, which carriers plan to use in 5G [29]. A European Parliament report "5G Deployment: State of Play in Europe, USA, and Asia" explains how 5G radio emissions are different from those of previous generations because of their complex, highly focused, beam-formed transmissions, and that “it is not possible to accurately simulate or measure 5G emissions in the real world” [30].

Environments with very low RFR exposures can be achieved by choosing wired and fiber-optic cable connections, to buildings and throughout buildings. In fact, RFR is not only unnecessary for a “smart building;” wireless options will not match the bandwidth or reliability of fiber-optic or other cable options (“wired”) [31]. Wired options are faster and more secure, and require much less energy to operate [29,32], making them safer for human and environmental health.

4. Adverse health effects of RFR

4.1. Introduction

In many countries, guidelines and standards to protect the public from adverse effects of radiofrequency radiation (RFR) are based on an assumption that harm results only from excessive heating of tissue (thermal effects); however, numerous scientific publications document that RFR affects living organisms at exposures within regulatory parameters, at “non-thermal” levels.

“Microwave assisted chemistry” accelerates particular chemical reactions with low levels of RFR [33,34], and has been commercialized [33,35]. In living systems, the acceleration of some chemical reactions would cause molecular damage, chemical imbalances and dysfunction, and is consistent with observations of significant effects in humans, animals, plants and isolated cells.

Effects observed in studies of humans exposed to non-thermal levels of RFR include: cancer; early childhood developmental problems; brain, sperm and DNA damage; as well as electromagnetic hypersensitivity.

4.2. Cancer

4.2.1. RFR classified as a possible human carcinogen

The adequacy of RFR regulatory limits was challenged in 2011 when an expert panel convened by the International Agency for Research on Cancer (IARC) of the World Health Organization classified RFR (100 MHz–300 GHz) as a Group 2B, *possible* human carcinogen, largely based on the human epidemiological evidence of increased risk of glioma [36,37], a type of brain cancer. This classification includes wireless frequencies from all types of RFR-emitting devices, including Wi-Fi. In 2019, an IARC advisory group recommended reassessment of the 2011 classification, in light of recent animal research [38].

4.2.2. Subsequent evidence supports upgrading the IARC classification

In 2018, Miller et al. concluded that as a result of human epidemiology, and animal studies published following the IARC 2011 panel meeting, RFR should be categorized as a Group 1 *known* human carcinogen [39]. Hardell and Carlberg came to the same conclusion [40]. Tobacco smoke and asbestos are in Group 1.

The main human evidence for this proposed classification upgrade is a large French epidemiological study [41], as well as a meta-analysis of pooled case-controlled studies in Sweden [42]. In addition, a 2018 Israeli occupational exposure study concluded that overall the evidence “make[s] a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1)” [43]. A case series also reports breast cancers associated with carrying a cell phone in the bra [44].

Canadian data (2001–2004) showed evidence of doubled risk of developing glioma for adults who used cell phones for 558 lifetime hours or more [45]. Consistent with the increasing use of cell phones, there was a statistically significant increase in incidence of primary malignant brain and central nervous system tumors in children and adolescents in the U.S. between 2000 and 2010 [46], and brain tumors subsequently became the most common malignancy in children and adolescents, with disease shifting to more aggressive gliomas [47].

Further supporting evidence came from three recent RFR rodent studies. The first two studies reported higher incidence of cancers in male rats exposed to RFR: 1) a $30 million study by the U.S. National Toxicology Program (NTP) of the National Institutes of Environmental Health Sciences (NIEHS), studied radiation simulating RFR intensity from cell phones [48]; and 2) a study by the Italian Ramazzini Institute [49] that was conducted at lower intensities (below FCC limits) designed to mimic radiation from cell towers. The tumors found in these large-scale studies were of the same histotype as in some human epidemiological cell phone studies.

A third large study demonstrated increased initiation and acceleration of tumor growth with RFR when the exposure was in conjunction with a cancer-causing chemical [50], replicating findings of a 2010 study [51].

4.3. Early life stages

During their rapid development, the embryo, fetus, infant and child are more vulnerable to many environmental insults, and impacts are potentially lifelong. Various life stages have different vulnerabilities

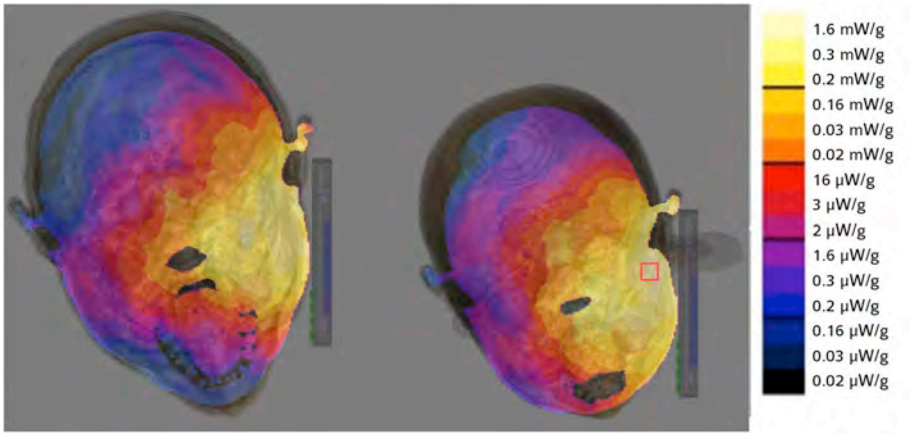

Fig. 2. Specific Absorption Rate (SAR) in adult and child (age 6 years) male heads with phone in talk position. The scale is 50 dB with 0 dB = 1.6 mW/kg. From work of Claudio Férnandez, 2018 [20] (used with permission of Environmental Health Trust).

and susceptibilities to RFR [52,53,54,55]. Modeling indicates that children absorb substantially higher RFR doses from cell phones, in deeper brain structures, than do adults (Fig. 2) [20]. Research has also found proportionately higher doses to tissues in children compared with adults, from wireless laptops and utility meters [56,57,58].

Research has linked exposure during pregnancy to adverse effects. The authors of a case-control study published in 2015 stated, "use of mobile phones can be related to early spontaneous abortions" [59]. Maternal mobile phone use during the first trimester of pregnancy may contribute to slowing or halting of embryonic development [60], possibly due to effects on membrane receptors in human amniotic cells [61]. A 2019 study of over 55,000 pregnant women and infants in four countries (Denmark, the Netherlands, Spain and Korea) linked maternal cell phone use during pregnancy with shorter pregnancy duration and increased risk for preterm birth [62].

Behavioral problems have been associated with prenatal and postnatal cell phone exposure. In five cohorts, Birks et al. found cell phone use by a pregnant woman to be associated with an increased risk for behavioral problems, particularly hyperactivity/inattention in her child [63], and Divan et al. reported behavioral problems in children up to seven years of age [64,65]. Studies of children and adolescents report possible associations of wireless technology use with addictions and depression [66], fatigue [67], altered baseline thyroid hormone levels [68], and poorer well-being [69,70]. Sage and Burgio discuss the damage from low levels of RFR to genetic material including DNA and nuclear structures in the cell, and potential mechanisms of child neurodevelopmental impairment [71].

A Yale University study found that when mice were exposed *in utero* to cell phone radiation, they had impaired memory and increased hyperactivity in adulthood [72].

Not only can RFR act along with carcinogens to promote tumor development [50], it also may synergize with toxic chemicals in other ways. For example, in a study of Attention Deficit Hyperactivity Disorder in children, ADHD was associated with mobile phone use for voice calls only in children who were also exposed to relatively high lead levels (lead is an established, potent neurotoxin) [73]. Further synergistic effects between RFR and various chemicals including nutrients (i.e., both beneficial and adverse) are described in a 2016 review by Kostoff and Lau [74].

4.4. Sperm

Three systematic reviews published from 2014 to 2016 [75,76,77] reported significant adverse effects on sperm quantity and quality, as well as DNA damage, from everyday RFR exposures. Animal studies reported testicular damage at 0.002 W/kg [78] and sperm damage at 0.024 W/kg SAR values [79].

4.5. Wi-Fi and other ambient RFR

Much of the RFR research reported thus far has focused on exposures to users of devices in close proximity (e.g., cell phones). More distant sources such as Wi-Fi access points or cell towers generally contribute less to exposures because RFR drops off quickly with distance from the source, following the "inverse square law" (levels are a quarter at twice the distance; one-ninth at three times the distance; etc.). Although exposure intensities from distant sources are usually low compared with devices in close proximity, simultaneous exposures are complex as devices connect to networks, people move around, and RFR may be reflected or absorbed by building materials, other surroundings, and inhabitants [80,81].

At any particular point in space and time, electromagnetic exposures are the sums of electrical and magnetic field vectors [7]. Of importance for health, effects (e.g., oxidative stress and consequences in tissues) may be cumulative over time, and these effects are modulated by other exposures to chemicals (nutrients as well as adverse substances) and other stressors [8]. 5G is to be deployed with multiple directional antennas, but future exposures are not well characterized [30], and less is known of future health outcomes from this technology.

In a comprehensive literature review, Pall states that "Wi-Fi causes oxidative stress, sperm/testicular damage, neuropsychiatric effects including EEG changes, apoptosis [cell death], cellular DNA damage, endocrine changes, and calcium overload," that the effects from continuous, long-term exposure may be cumulative, and that pulsed signals are more biologically active than a smooth carrier wave [82].

Impaired brain development and cognitive function, as well as addictive behaviors in children and adolescents are observed with exposure to RFR [71,81]. In a study of exposure to RFR in schools, 18 teachers wore "exposimeters" to continuously record exposures to a spectrum of RFR. Mean exposure levels varied widely according to activities in the classroom, but peak measures were up to 83,000 μW/m^2 [81]. The highest levels occurred when students were streaming video, and the lowest occurred when the teacher had a wired Internet connection in a classroom far from Wi-Fi access points and students' laptops were in airplane/flight mode [81].

Measurements of ambient RFR have been carried out in other settings, including a train station [80] and other Stockholm landmarks [83], and neighborhood surveys from a car [84]. Ambient measurements correlate moderately with personal monitoring.

In an extensive review, Dürrenberger et al. characterized RFR and emissions from infrastructure in micro-environments [85]. Exposures are typically underestimated, and experts, officials and citizens may be surprised at the differences among venues. These uncertainties make it statistically difficult to detect health effects, resulting in under-estimation of harms as well [86]. Although exposures generally meet government regulatory limits, they exceed precautionary recommendations [80]. Recent reviews of RFR assessments found higher levels in offices and public transportation [87,88].

Researchers in a Bavarian village followed a natural experiment over 18 months, when a central cell tower was installed [89]. They found dose-dependent dysregulation of stress hormones, according to peak RFR exposure measured at the doorstep [89].

Effects reported in RFR studies may be complex and non-monotonic (i.e., effects occur at lower exposure levels that do not manifest at higher levels) [48,50,90]. It is known that biological mechanisms are established whereby chemicals cause complex dose-responses, particularly for hormone-related effects (the endocrine system) [91,92].

4.6. Electromagnetic hypersensitivity (EHS)

As with other environmental exposures, some people are more susceptible (sensitive or intolerant) and overtly affected by RFR. Electromagnetic hypersensitivity (EHS) is also commonly termed electrical sensitivity, electrohypersensitivity, idiopathic environmental intolerance, or (historically) microwave sickness.

Common symptoms of EHS include headaches, cognitive difficulties, sleep problems, dizziness, depression, fatigue, skin rashes, tinnitus and flu-like symptoms [93,94]. Adverse reactions to wireless devices range from mild and readily reversible to severe and disabling, and individuals must greatly reduce their exposures to sources of electromagnetic radiation [95,96,97].

Surveys conducted in several countries at times ranging from 1998 to 2007 estimated that approximately three to thirteen percent or more of the population experience symptoms of EHS [98–101].

As well as being difficult to manage in the modern world, EHS is typically unexpected. The theory that EHS is merely a "nocebo" response – that it results from suggestion and worry over possible effects of electronic devices – is the opposite of experience. In a study of 40 people, their EHS was only recognized following a period of illness and self-experimentation [102]. Further research has confirmed that lived experience is not consistent with the nocebo hypothesis [103].

EHS is recognized as a disability and is accommodated in the U.S.

under the *Americans With Disabilities Act* [104]. Sweden recognizes EHS as a functional impairment [99]. In Canada, the condition is included under environmental sensitivities [97,105]. Legal cases for compensation, disability pensions and accommodation in various countries are discussed in Section 6.

Physicians' organizations' research, experiences, practices and statements over the years were summarized by the European Academy of Environmental Medicine (EUROPAEM) in 2016 [4]. Sensitivities vary among individuals, and symptoms may also occur with exposures outside the RFR range. The consensus of the *EUROPAEM EMF Guideline* is that the most important action for treatment and management of EHS is reduction and avoidance of pertinent exposures in locations where significant amounts of time are spent, especially in sleeping areas. Other recommended measures include a suite of healthy lifestyle measures such as nutrition, stress reduction and measures to avoid toxicants, as well as to reduce levels of toxicants sequestered in the body [4].

4.7. Rigorous systematic review of the scientific evidence, for public health, policy and regulation

As evidenced here, contributions of RFR to adverse effects on public health may be substantial [106,107]. Public policy, and safety guidelines and standards, should be based on all of the best available scientific evidence; however, there has never been a systematic review conducted according to international best practices [108] of the RFR evidence, upon which to base exposure guidelines.

Influence of biases and conflicts of interest has been documented as a serious concern for international authoritative bodies such as the World Health Organization-International Electromagnetic Fields (EMF) Project, and the International Commission on Non-Ionizing Radiation Protection [109–111]. The same is true for the national authorities in Australia [112], Canada [113–115], the European Commission [116], the United Kingdom [117] and the U.S [118]. Bias in original scientific studies is evident in that studies funded by industry are less likely to identify adverse effects than those that are independently funded, and even less likely to conclude that adverse effects exist [119–121].

An important step towards resolution of the adequacy of guidelines and standards to protect public health, as well as policy and practical responses for individuals who experience EHS, would be a thorough systematic literature review conducted by independent, knowledgeable specialists. This would examine all of the RFR literature dating back to the identification of health concerns with the development and deployment of radar during World War II, including the studies in the 1971 review by Dr. Zorach Glaser [122].

Key features of this type of review include that all steps and findings must be transparent, such as bibliographic search methods, study selection, data extraction and meta-analyses, quality assessment and the weight of evidence analysis [108].

5. Environmental impacts of cell tower and radiofrequency radiation

Built and natural environments are interconnected. Biological systems are integrated, complex and operate using minute electrical charges combined with precise chemical signals. These mediate complex functions such as development, reproduction and cognition. Recent research has demonstrated adverse effects of radiofrequency radiation (RFR) on environments and wildlife, including birds, amphibians, insects, fish, mammals and plants [123–125]. For example, trees near cell towers can become visibly unhealthy on the side facing a cellular antenna, and can die prematurely [126].

A diverse array of species depends upon the Earth's low-level magnetic field to navigate for migration, homing, breeding, foraging and survival. RFR can have significant long-term impacts on the natural environment via disruption of normal positioning and orientation abilities as well as other complex cellular and biologic processes. Incremental effects may be only slowly recognized as species and ecosystems decline.

Small deposits of the iron-containing mineral magnetite act as magnetoreceptors to sense the Earth's magnetic field in a variety of organisms, including bacteria, insects, fish, birds and mammals [127–129].

Some bird species are strongly influenced by the low-intensity magnetic fields of the Earth for directional reference. Newer studies suggest that light-dependent cryptochrome photo receptors in birds' eyes are also sensitive to magnetic forces, and communicate with the brain [130,131].

RFR can interfere directly with magnetoreception in birds, disabling their avian magnetic compass [132]. A series of double-blinded studies replicated over several years demonstrated that migratory European robins lost their ability to orient and navigate in a city with high background "electromagnetic noise" and broadband frequencies [133]. Effects can be complex, as illustrated by findings that some birds can be more sensitive to weak broadband than to stronger fields [134,135].

Bees use magnetite crystals in their abdomens for navigation [136]. This sensory modality can be disrupted by electromagnetic fields, causing a loss of colony strength [137–140]. Scientists are increasingly concerned about the impacts of wireless radiation on the worldwide decline of domestic bees and colony collapse disorder [141,142]. Other insects are also adversely affected by RFR [142–145].

Review articles indicate that the weight of evidence is that RFR acts as an environmental toxin with ecosystem-wide harm from increasing ambient RFR emitted by cell towers and other RFR infrastructure [146–152].

6. Liability

Some industry liability insurance providers do not provide coverage against adverse health effects from RFR. Lawsuits for RFR health-related conditions are underway, and some have been successful in different countries.

6.1. Insurance industry and liability related to radiofrequency radiation

Insurers have declined to provide coverage to wireless product manufacturers and U.S. mobile operators for health damages from their products and networks since the early 2000s [153]. Insurers often exclude or limit coverage for the risk from electromagnetic fields (EMFs) posed by commercial general liability policies, decline policyholders in the wireless industry, and only provide coverage via pollution liability policy enhancements.

Insurance authorities also address the risks of electromagnetic fields. In 2014, the Swiss RE report *New emerging risk insights* listed the potential impact of the "Unforeseen consequences of electromagnetic fields" as "High" and examined further incremental risk associated with smart cities [154]. In its 2019 update, Swiss Re identified the top two emerging risks to be "digital technology's clash with legacy hardware, and potential threats from the spread of 5G mobile networks" [155].

In 2010, the Emerging Risk Team of Lloyds issued a white paper [156] indicating that the potential risks to insurers from health damage claims associated with cell phones and wireless radiation are comparable to those posed by asbestos. The 2013 Lloyds Risk Index lists "harmful effects of new technology" as an increasing environmental risk [157].

Some corporate insurance policies feature a general exclusion section that explicitly prohibits liability for injury or property damages from electromagnetic fields. This is considered to be a standard across the North American insurance industry [158].

Insurance company policies will often define electromagnetic radiation as a "pollutant." According to the AT&T Mobile 2012 Insurance policy, "Pollutants" mean: "Any … artificially produced electric fields,

magnetic field, electromagnetic field, sound waves, microwaves, and all artificially produced ionizing or non-ionizing radiation and waste." [159]. Policy enhancements can be purchased to cover environmental pollutants, which include EMFs [160,161].

The Austrian Worker's Compensation Board (AUVA) commissioned the Vienna Medical University to research effects of cell phone radiation on the brain, immune system, DNA and proteins, and published a series of reports that present the research evidence and conclude by recommending precautions to reduce exposure [162,163].

6.2. Summary of 10 K reports

Publicly traded companies issue annual 10-K reports to the U.S. Securities and Exchange Commission, summarizing the company's financial performance and status. Mobile operator reports identify potential liabilities for health damages from exposure to wireless devices as a risk, and provide no assurances that their products or equipment will be safe in future years.

Crown Castle states in their 2017 Annual Report [164], "If radio frequency emissions from wireless handsets or equipment on our communications infrastructure are demonstrated to cause negative health effects, potential future claims could adversely affect our operations, costs or revenues."

Verizon's 2017 Annual Report [165] states, "… our wireless business also faces personal injury and wrongful death lawsuits relating to alleged health effects of wireless phones or radio frequency transmitters. We may incur significant expenses in defending these lawsuits. In addition, we may be required to pay significant awards or settlements."

6.3. Lawsuits related to electromagnetic fields

In the U.S., the first cell phone cancer case was filed in 1992 and was followed by a series of cases that were either settled by confidential resolutions or dismissed due to lack of evidence or lack of authority of the court [166]. At the time of writing, there are thirteen active consolidated cases with defendants alleging their brain cancers were from cell phone use [167]. In 2017, Italy's highest court recognized a causal link between development of a brain tumor and cell phone use, and awarded social security payments [168].

Internationally there are several lawsuits related to cell phones and cancer and disability from EMF exposures. For example, Australian [169] and Spanish [170] courts have awarded disability to workers claiming sensitivity to electromagnetic radiation.

In January 2019, an Italian court ordered the government to launch a campaign to advise the public of the health risks from mobile and cordless phones [171].

7. International actions to limit public exposure to RFR

Some international governments have passed legislation (Table 1), and health and environmental authorities in numerous countries, regions and cities have issued recommendations (Table 2) to reduce exposure of the public to radiofrequency radiation (RFR). Measures frequently focus on children's vulnerabilities [172], identifying "sensitive areas" with stricter exposure limits where the young sleep, play and learn.

5G, the next generation of wireless technology, will utilize frequencies presently in use, plus higher frequency millimeter waves not previously used for commercial telecommunications. Regional governments, such as the Cantons of Geneva, Vaud and Neuchâtel in Switzerland, are issuing decrees calling for moratoriums on the rollout of 5G technology until the health effects are better understood [173–175].

7.1. Regional U.S. Guidelines and recommendations to limit RFR exposure in schools

In addition to national policies to reduce children's EMF exposures, several authorities in the U.S. have issued guidelines for schools. In 2014, the Collaborative for High Performance Schools (CHPS) [189], the leading organization for healthy schools in the U.S., first published recommendations to minimize exposure to both Extremely Low Frequency (ELF) magnetic fields and RFR. Criteria for "Low-EMF Best Practices" include:

- providing a wired local area network (LAN) for Internet access throughout the school;
- disabling all wireless transmitters on all devices;
- ensuring that all laptops or notebooks have an Ethernet port and a single physical switch to disable all wireless radios;
- providing easily accessible hard-wired phones for teacher and student use;
- prohibiting the installation or use of DECT cordless phones; and
- prohibiting the use of cell phones and other personal electronic devices in instructional areas.

In 2016, the New Jersey Educational Association [190] and the Maryland Children's Environmental Health and Protection Advisory Council (CEHPAC) [191] also issued recommendations to reduce RFR in school classrooms, including, "if a new classroom is to be built, or electrical work is to be carried out in an existing classroom, network cables can be added at the same time, providing wired network access with minimal extra cost and time."

Measures to reduce exposures regarding personal devices are listed in the Appendix.

8. Recommendations for the building industry

Rapidly evolving technology is resulting in an evolution of building systems, moving to integration of air quality control, power management, surveillance and access, communications and data management, etc. in "smart" buildings. Although wireless "Internet of Things" may be popularized as central to "smart" infrastructure and conveniences, key features can readily be physically connected non-wirelessly. Sinopoli detailed essential elements of design, construction (installation of cables/wiring), integration and operation of networked systems to improve indoor environments and function, and achieve efficiencies in indoor spaces [192].

Electromagnetic interference is another reason to minimize radiofrequency radiation RFR [193]. It can degrade operation of wireless systems (e.g., Wi-Fi), and sensitive electronic equipment (wired or wireless) such as for entertainment recording or medical applications. Addition of cell towers in proximity to unshielded areas (indoors or outdoors) can also cause signal interruptions and static. In the extreme, wireless systems can be shut down by malicious attack with strong signals "drowning out" signals on designated frequencies.

Health care policies have evolved to protect operation of essential equipment. Mobile phones were initially forbidden in hospitals due to risks of interference with operation of sensitive equipment. Based on limited study, it is now recommended that wireless devices be kept at a distance from sensitive equipment (e.g., in intensive care units [ICUs]) [194]. Today, wireless access for patients and the public is often provided in hospitals, and wireless devices are common in healthcare [195]. There is no evidence of clinical benefit, and reviews did not investigate potential clinical harms [195].

For any systems that are not "wired," architects, builders, owners and inhabitants all must operate within constraints of regulated RFR exposure levels. RFR exposure limits vary among jurisdictions, with the highest permitted personal exposures in the U.S.A. and Japan. Many countries adhere to the International Commission on Non-Ionizing

Table 1
Examples of national legislation limiting RFR.

Year	Country and Reference	Legislation
2016	French Polynesia [176]	Banned marketing of cell phones to children. Prohibited wireless in nursery schools.
2015	France [177]	Banned Wi-Fi from nursery schools. Decreed that in schools Wi-Fi be turned off as default, unless the teacher uses it for specific instruction. Wi-Fi hotspots must be labeled.
2014	Korea [178]	Mandated SAR labeling on cell phones and portable devices. Public health recommendations to reduce exposure to cell phone radiation.
2013	Belgium [179]	Banned marketing of cell phones to children below age 14. Phones designed for children below age 7 years are prohibited from sale.
2012	India [180]	Limited RF-EMF exposure levels from cell antennas to 1/10th of International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. Required SAR labeling on phones.
2012	Greece [181]	Forbade installation of mobile phone base stations on the premises of schools, kindergartens, hospitals or eldercare facilities.
2010	France [182]	Required that cell phones be sold with a headset and recommendation to limit exposure to the head. Cell phone advertising aimed at children below age 14 years was banned.

Radiation Protection (ICNIRP) recommended guidelines for power flux density, electrical fields and SAR for various frequencies [196]. Exposure limits range widely, for example in terms of power density at 900 MHz, as summarized in Fig. 3.

8.1. Building guidelines for lower electromagnetic field (EMF) exposures

Green building standards for occupants' health put great emphasis on indoor air quality, and the electromagnetic characteristics of the indoor environment are beginning to gain more widespread attention. This is exemplified by the aforementioned CHPS "Low-EMF Best Practices" in the U.S [189].

In Austria, Germany and Switzerland, however, electromagnetic fields and radiation exposures have long been a green building consideration. In Germany, the first precautionary exposure guideline for sleeping areas (SBM-2015) [28] was issued by Baubiologie Maes in cooperation with the Institute of Building Biology and Sustainability (IBN) in 1992. Based on thousands of electromagnetic assessments, radiofrequency radiation (RFR) levels in the bedroom below 0.1 $\mu W/m^2$ are considered "no anomaly." RFR levels above 1000 $\mu W/m^2$ (1 mW/m^2) are considered an "extreme anomaly."

The Total Quality Building Assessment Tool (TQB) is a widely used green building rating system [199], addressing a broader range of parameters than the Leadership in Energy and Environmental Design (LEED) rating system [27]. Since its inception in 2001 the TQB tool has included low-intensity EMFs and radiation – both low-frequency alternating magnetic fields and RFR. The TQB awards points in the planning and final testing stages for low levels of RFR.

The European Academy for Environmental Medicine (EUROPAEM) EUROPEAM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses [4] details recommendations for precautionary threshold electromagnetic exposure levels, including for RFR.

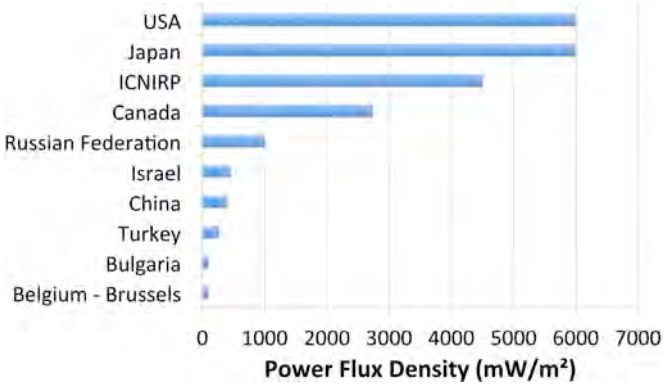

Fig. 3. International RFR power flux density exposure limits at 900 MHz [197,198].

To put these recommendations into context, the precautionary thresholds fall somewhere between the low natural background level and official exposure limits (Fig. 3). For comparison, Table 3 summarizes prudent, precautionary recommendations of European specialists.

The guiding principle of "as low as reasonably achievable" (ALARA) was introduced as early as the 1950s to protect against ionizing radiation [200] and holds true for many toxicants to the present day [91], including RFR [201]. RFR levels in indoor environments can be minimized by integrating the principal of ALARA (minimize emissions and exposures, maximize distance and use protection) [202] into selection of the building location, design and materials, as well as choices of electrical, monitoring, control, surveillance and other systems and services.

Table 2
Examples of national policies, public health advice and medical organization recommendations.

Year	Organization and Reference	Advice and Recommendations
2017	Athens Medical Association [183]	Sixteen recommendations to reduce human exposure to wireless radiation
2016	France - National Decree [184]	Reduced EMF exposure of workers, especially pregnant women
2016	US - American Academy of Pediatrics [185]	Ten recommendations to reduce exposure to cell phone radiation
2015	Cyprus National Committee on Environment and Child Health [186]	Public service videos and brochures for families about how to reduce cell phone and wireless exposure
2009, 2015	Finland - Radiation and Nuclear Safety Authority [187]	Recommendations to reduce RFR exposure, especially of children
2011	Parliamentary Assembly, Council of Europe [188]	"The potential dangers of electromagnetic fields and their effect on the environment" recommends As Low As Reasonably Achievable (ALARA), awareness, precautionary approaches, transparency, research, etc.
2010	France - National Public Health Agency [182]	An awareness campaign about ways to reduce RFR exposure

Table 3
Precautionary guidance RFR exposure levels [4,199].

		Exposure to 900–1800 MHz RFR (mW/m^2)
TQB Tool	Planning stage	
	10 points (best)	≤ 1
	5 points	≤ 3
	0 points	> 3
	Final stage	
	10 points	$S \leq 0.01$
	8 points	$0.01\ mW/m^2 < S \leq 0.1$
	6 points	$0.1\ mW/m^2 < S \leq 1$
	4 points	$1\ mW/m^2 < S \leq 3$
	0 points	> 3
EUROPAEM 9001800 MHz		
	Daytime	0.1
	During sleep	0.01
	Sensitive Populations	0.001
Natural Background		0.000000001

8.2. Strategies to eliminate or minimize RFR exposures from sources within buildings

As exemplified in section 8.1, engineers, architects, designers and planners have a unique opportunity to create healthier living, learning and work environments by reducing use of wireless technologies and thereby reducing levels of RFR. Although it is simpler, preferable and less expensive to implement RFR-free options during the initial design and construction stages, existing buildings represent many opportunities for improvements.

8.2.1. Connect necessary technologies with cables

An important first step to minimize levels of RFR within buildings is to eliminate indoor sources of RFR, and to connect all technologies via wire or fiber cable ("wired").

Consider alternative approaches to wireless technology. Recommendations include:

- Neighborhood infrastructure with cable access for high-speed, wired telephone and Internet;
- Within buildings use cables, preferably shielded, in Local Area Networks (LAN) to provide wired access points for all networking and data transmission, including wired connections for modems, routers, Internet and media; lighting, heating, ventilation, air conditioning (HVAC), thermostats and humidistats; surveillance and security systems; fire detection and response (e.g., sprinklers); pool equipment such as pump and treatment controls, etc.;
- Install easily accessible wired (not cordless) phones and prohibit installation and use of cordless phones;
- Throughout the building, provide connections to hardwired CAT6 or CAT7 Ethernet cables, preferably shielded, to service devices such as computers, tablets and other devices. Use wired peripherals and accessories. Ensure that all wireless features are turned off or disabled;
- Install wired RJ11 phone jacks for corded and landline telephones; and
- Use analog, non-transmitting utility (water, electricity, gas) meter options, that do not transmit data wirelessly.

8.3. Strategies to minimize the RFR exposures from external sources

8.3.1. Building location and landscaping

To achieve very low RFR levels, new buildings may be located in a low-RFR environment, for example at a distance from cell towers, radio and TV broadcast towers, and radar sites (e.g., airports). Evaluate the proposed location with professional grade RFR equipment to determine ambient RFR levels and sources. Sites in valleys may be at least partially protected from regional sources of RFR by surrounding hills, as may underground structures by intervening earth that absorbs RFR, depending upon composition and moisture level [203]. Conductivity and permittivity of soil increases with moisture content [204]; MW radiation is strongly absorbed by water.

Vegetation, with its significant water content, will absorb some RFR. While foliage of tall deciduous or evergreen trees may present challenges to wireless service providers, absorption of RFR from nearby antennas may also harm vegetation [126].

8.3.2. Building materials and shielding

RFR may be either reflected or absorbed by building materials, and there is a continuum of how opaque building elements are to RFR [204]. Shielding with highly absorbing or conductive materials can be very effective to reduce RFR originating from outdoors sources [205].

Many building materials such as wood and wallboard are largely transparent to present day RF signals, but research is intensifying on RFR-absorbing materials and fabrics that contain metals or carbon based substances (e.g., nanotubes) [206,207]. Construction materials are less effective barriers to RFR in the MHz and lower GHz frequency ranges, as currently used for cell phones, than for higher GHz frequencies planned for 5th generation (5G) technologies [208].

Absorption rather than reflection offers clear advantages for protection from RFR, and considerable relevant research has been devoted to materials that absorb radar [205]. Thick layers of dense building materials such as concrete offer some potential to absorb RFR and thereby reduce levels, particularly in the GHz range. Early research indicating high attenuation [209] was not precisely replicated with drier samples.

Conductive materials must be used with care and caution because reflections may result in unanticipated exposures. Totally enclosing a space with reflective materials (e.g., metal) results in a "Faraday cage." Radiation from sources within the "cage" reflects from one surface to another and this can result in higher local levels than would be the case if RFR was transmitted or absorbed by structural materials and furnishings.

To shield against incoming RFR from cell antennas, Wi-Fi networks and radio broadcast towers, shielding may be integrated across the entire building envelope or selected rooms or zones of a building.

Low-E windows coated with a transparent layer of metal oxides (developed to reflect infrared to retain heat in buildings and reflect ultraviolet light from the outdoors) and metals reflect RFR. Exterior shielding may be achieved with metal cladding/roofing, metal window and door frames, metal or metal-clad doors, low-E windows, metal screens, RF window film, and fine metal mesh or radiant barrier foil integrated into the building envelope. Further options indoors include high quality carbon-based shielding paints or fine metal mesh, and RF-shielding drapes/sheers. Conductive shielding materials including paint must be electrically connected and properly grounded.

It is essential to recognize that within shielded spaces, devices must have all wireless functions turned off. Poor network connections for cell phones will result in stronger RFR signals from the device itself, with potentially four-fold higher exposure to the user [210], and reflections from metal shielding may result in yet higher exposures. Thus, prominent explanatory safety notices are necessary to ensure that all cell phones are "off," set to "airplane mode," or are left outside of the low-RFR shielded zone. Options to meet occupants' needs include provision of accessible corded landline telephones to which cell phone calls can be forwarded, and provision of wired connections for devices.

Whatever options are used to achieve low RFR levels, it is necessary to verify final results with measurements using an RFR meter. RFR from equipment and exterior sources, along with reflections, and interactions with conductive infrastructure can result in complex, unanticipated patterns of electromagnetic fields, including hotspots [193,208]. Periodic checks are necessary to ensure that additional equipment,

furnishings or modifications, indoors or outdoors have not increased RFR levels.

Each make and model of RFR meter or measurement instrumentation has different specifications. To confirm the effectiveness of an RFR meter, obtain a third-party calibration report from a certified testing facility.

8.3.3. Partial RFR-Reduction measures for internet connectivity in buildings

In homes, schools, and workplaces, the installation and exclusive use of wired Internet access and electronic communication among devices mitigates the RFR emissions from internal network systems.

During any time that a wireless function is enabled, on stationary or mobile equipment, routine signals to maintain connections will expose building occupants to RFR, whether or not the device is actually being used.

In situations where decision makers decide not to hardwire a building immediately and instead continue with wireless connectivity, some partial measures may partially reduce unnecessary exposure. Importantly, these partial reduction steps do not equate with complete RFR mitigation, do not ensure safety for occupants, and do not reduce liability.

Recommendations include:

- Connect routers to a power source using a timer, to power off when not routinely in use, such as at bedtime;
- Wireless routers and access points should have an easily accessible switch to turn them off when not in use;
- Choose routers that can accommodate wired input, equipped with an accessible on/off switch for wireless features, and use a wired connection to a wired modem, to provide Internet connection when the wireless function is turned off;
- Avoid modems that also act as public “hot spots;”
- Do not install wireless access points near bedrooms or other highly or frequently occupied spaces;
- Clearly label wireless access points and areas where wireless antennas are in use;
- Use wired connections for HVAC monitoring and control, lighting, security and other fixed monitors and controllers;
- For improved security and lower carbon footprint, as well as reduced RFR, access data and controllers via a wired connection;
- If a wired analogue utility meter is not an option, mount the wireless meter at a distance, shield appropriately and direct signals to where they are read. Locate wireless meters away from high-use areas, particularly bedrooms; and
- If the building is mostly shielded, but has an unshielded zone for wireless device use, ensure that there is signage informing people: 1) of the RFR exposures along with wireless access (and alternatives onsite); and 2) the need to have all wireless functions turned off in shielded zones.

Implementation of partial measures will continue to expose occupants to RFR at levels associated with adverse effects. Measures such as turning off wireless features when not in use still result in RFR exposures, are not ALARA, and ideally will only be used in the interim while wiring plans are being developed and implemented.

8.4. Sensitive and vulnerable individuals

All of the above and more may need to be implemented to reduce RFR adequately in indoor and outdoor environments, to accommodate sensitive individuals. This will often require engaging an EMF expert, because the behavior of electromagnetic fields, currents and radiation is complex and difficult to predict. Sensitive individuals must be consulted throughout the duration of any renovation or building project, because individuals may react differently to various electromagnetic exposures. These individuals may also be sensitive to indoor air quality, so they must be involved in selection of materials for construction or retrofitting [2].

8.5. Challenging the business case of wireless systems

Not only are multiple risks invoked by choices of wireless instead of wired technology, there are many advantages to wired solutions.

Wireless networks [29,211]:

- continue to be about 100 times slower than wired systems;
- are unreliable, and more prone to both latency and delay issues;
- consume significant amounts of energy – more than wired – and are not sustainable;
- increase the points of vulnerability; and
- increase the security and privacy risks to personal and business data.

Some companies are cautioning that deployment of wireless 5G and beyond will be hampered by current regulatory power density exposure limits [212,213].

9. Discussion and conclusion

The breadth of peer-reviewed scientific research demonstrating biological effects of radiofrequency radiation (RFR) below current guidelines and standards highlights the need to further develop and codify pertinent building technology standards and guidance. Public health risks, accessibility needs, industrial liability and international precautionary actions indicate that RFR is an important performance parameter in building science.

Parallel with rapid innovation in wireless technologies, and the increasing RFR both inside and outside building structures, building science must also innovate to include alternative, physically connected technologies and systems. This is important to achieve accessibility and a building's success. Ensuring that the health and safety of occupants are not compromised requires those in the building science professions to develop and apply needs and means assessments, as well as best practices for methods and models for communications, with RFR wireless technology as a less-preferred option.

Research and knowledge transfer are needed to develop, publish, and encourage compliance with explicit directions for the integration of wired communications technologies in the design, planning, engineering, construction, operation and life cycle of a building.

Building science has embraced ecology and sustainability as core tenets in building performance. Currently, modern technologies minimizing RFR exposures offer an under-addressed opportunity for “smart” buildings also to be healthy – for their occupants, and for natural and built environments.

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Appendix

General Safety Tips to Reduce Radiofrequency Radiation (RFR) Exposure from Personal Devices

- Keep cell phones away from the head and body, and keep wireless devices at a distance, and off of laps.
- Make only short or essential calls on cell phones.
- Use text messaging instead of voice calls whenever possible.
- As much as possible power off phones and personal digital devices, or set on airplane mode with Wi-Fi, Bluetooth, Data, Mobile Hotspot and Location off.
- Avoid sleeping next to cell phones or wireless devices; power them

off at night. If a cell phone must be used as an alarm clock, turn the phone to airplane mode, or use a separate battery-powered clock.
- Keep non-prescription electronics out of bedrooms. If you depend upon medical devices with wireless functions, check how often they may be set to “airplane mode,” and ask your health care provider about adequate alternatives that do not emit RFR.
- Avoid charging phones and devices near beds.
- Use a corded (not cordless) home phone (wired [not wireless] VoIP or landline) whenever possible, especially for long voice calls.
- Pre-download videos and music rather than streaming.
- Minimize the number of apps running on wireless devices.
- Choose wired Internet connections instead of wireless systems, whenever possible. Provide wired Internet connections for others.
- If Wi-Fi cannot be entirely eliminated, put the Wi-Fi router on a timer to turn off when not needed (especially while sleeping).
- When digital devices are connected with wired Internet connections, turn off the Data, Wi-Fi and Bluetooth (in device settings) and turn off the Wi-Fi on the router.
- Request wired options and provide them to others, such as for computers, laptops, tablets, printers, gaming consoles and handsets, mouse, keyboards, video cameras, speakers, headphones, microphones and other accessories.

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References

[1] Ted J. Kesik, Building science concepts, WBDG - whole building design guide, http://www.wbdg.org/resources/building-science-concepts, (2016) accessed January 19, 2019.
[2] Indoor Air Quality Forum, National Research Council, Canada, module 13 - addressing chemical sensitivities, IAQ Forum, 2019, https://iaqforum.ca/iaqcanada/wp-content/uploads/2019/09/CCIAQB-Module-13-Addressing_Chemical_Sensitivities_Final_V2_Eng.pdf accessed July 3, 2019.
[3] D. Clements-Croome (Ed.), Electromagnetic Environments and Health in Buildings, Spon Press, Taylor & Francis Group, London and New York, 2004, https://www.researchgate.net/publication/279190350_Electromagnetic_Environments_and_Health_in_Building/link/558d597208ae634309f310f9/download.
[4] I. Belyaev, A. Dean, H. Eger, G. Hubmann, R. Jandrisovits, M. Kern, M. Kundi, H. Moshammer, P. Lercher, K. Müller, G. Oberfeld, P. Ohnsorge, P. Pelzmann, C. Scheingraber, R. Thill, EUROPAEM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses, Rev. Environ. Health 31 (2016), https://doi.org/10.1515/reveh-2016-0011.
[5] National Institute for Public Health and the Environment (RIVM), Comparison of international policies on electromagnetic fields, The Netherlands, https://www.rivm.nl/sites/default/files/2018-11/Comparison%20of%20international%20policies%20on%20electromagnetic%20fields%202018.pdf, (2018) accessed July 5, 2019.
[6] H. Fritzsche, M. Phillips, Electromagnetic radiation | physics, encyclopedia britannica, n.d. https://www.britannica.com/science/electromagnetic-radiation accessed July 2, 2019.
[7] National Collaborating Centre for Environmental Health, British Columbia Centre for Disease Control, radiofrequency toolkit for environmental health practitioners, Vancouver, BC, Canada, http://www.bccdc.ca/resource-gallery/Documents/Educational%20Materials/EH/Radiofrequency-Toolkit.pdf, (2014) accessed July 5, 2019.
[8] D. Davis, M. Sears, A. Miller, R. Bray, Microwave/Radiofrequency wireless radiation and human health: clinical management in the digital age, Integrative Environmental Medicine, Oxford University Press, 2017, pp. 223–251 https://oxfordmedicine.com/view/10.1093/med/9780190490911.001.0001/med-9780190490911-chapter-10.
[9] U.S. Federal Communications Commission, The FCC's 5G FAST Plan, Federal Communications Commission, 2019, https://www.fcc.gov/5G accessed July 3, 2019.
[10] F. Barnes, B. Greenenbaum, Some Effects of Weak Magnetic Fields on Biological Systems: RF fields can change radical concentrations and cancer cell growth rates, IEEE Power Electron. Mag. 3 (2016) 60–68, https://doi.org/10.1109/MPEL.2015.2508699.
[11] D.J. Panagopoulos, O. Johansson, G.L. Carlo, Real versus simulated mobile phone exposures in experimental studies, BioMed Res. Int. (2015), https://doi.org/10.1155/2015/607053.
[12] D.J. Panagopoulos, O. Johansson, G.L. Carlo, Polarization: a key difference between man-made and natural electromagnetic fields, in regard to biological activity, Sci. Rep. 5 (2015), https://doi.org/10.1038/srep14914.
[13] Radio Frequency Safety, Federal Communications Commission, https://www.fcc.gov/general/radio-frequency-safety-0, (2011) accessed November 17, 2018.
[14] National Council on Radiation Protection and Measurements (NCRP), Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, Bethesda, Maryland, 1986https://ncrponline.org/shop/reports/report-no-086-biological-effects-and-exposure-criteria-for-radiofrequency-electromagnetic-fields-1986.
[15] Radio Spectrum Allocation, Federal communications commission, https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation, (2011) accessed November 16, 2018.
[16] Federal Communications Commission, Guidelines for evaluating the environmental effects of radiofrequency radiation. ET Docket No. 93-62, FCC 96-326 https://transition.fcc.gov/Bureaus/Engineering_Technology/Orders/1996/fcc96326.pdf, (1996) accessed January 28, 2019.
[17] Health Canada, Government of Canada, Limits of human exposure to radiofrequency electromagnetic energy in the frequency range from 3 kHz to 300 GHz, Safety Code 6 http://www.hc-sc.gc.ca/ewh-semt/consult/_2014/safety_code_6-code_securite_6/final_finale-eng.php, (2015) accessed March 24, 2017.
[18] R. Matthes, J.H. Bernhardt (Eds.), Guidelines on Limiting Exposure to Non-ionizing Radiation: a Reference Book Based on the Guidelines on Limiting Exposure to Non-ionizing Radiation and Statements on Special Applications, International Commission on Non-Ionizing Radiation Protection, Oberschleißheim, 1999, https://www.icnirp.org/cms/upload/publications/ICNIRPemfgdl.pdf.
[19] OVERVIEW » SPEAG, Schmid & partner engineering AG, n.d. https://speag.swiss/products/dasy6/overview/ accessed July 5, 2019.
[20] C. Fernández, A.A. de Salles, M.E. Sears, R.D. Morris, D.L. Davis, Absorption of wireless radiation in the child versus adult brain and eye from cell phone conversation or virtual reality, Environ. Res. 167 (2018) 694–699, https://doi.org/10.1016/j.envres.2018.05.013.
[21] I.Y. Belyaev, Y.G. Grigoriev, Problems in assessment of risks from exposures to microwaves of mobile communication, Radiats Biol. Radioecol. 47 (2007) 727–732 https://www.ncbi.nlm.nih.gov/pubmed/18380333.
[22] D.J. Panagopoulos, O. Johansson, G.L. Carlo, Evaluation of specific absorption rate as a dosimetric quantity for electromagnetic fields bioeffects, PLoS One 8 (2013), https://doi.org/10.1371/journal.pone.0062663.
[23] O.P. Gandhi, Microwave emissions from cell phones exceed safety limits in Europe and the US when touching the body, IEEE Access 7 (2019) 47050–47052, https://doi.org/10.1109/ACCESS.2019.2906017.
[24] M. Arazi, Comments by the “Phonegate Alert” Association for the 20 June NTP Meeting Agenda Item: Studies of Cell Phone Radiofrequency Radiation Report on the 26-28 March 2018 Peer Review of NTP Technical Reports, U.S. National Toxicology Program, 2018, https://ntp.niehs.nih.gov/ntp/about_ntp/bsc/2018/june/publiccomm/phonegatealert_20180612_508.pdf accessed July 3, 2019.
[25] N. Hassam, D.H. Krueger, H. Krueger, D.D. Rasali, D. Fong, Prepared for the BC Centre for Disease Control (BCCDC), (2015), p. 38 http://www.bccdc.ca/resource-gallery/Documents/Educational%20Materials/EH/Radiofrequency-Toolkit.pdf.
[26] World Green Building Council, How can we make our buildings green? n.d. https://www.worldgbc.org/how-can-we-make-our-buildings-green accessed July 1, 2019.
[27] US Green Building Council (USGBC), LEED green building certification, n.d. https://new.usgbc.org/leed accessed July 1, 2019.
[28] Institut für Baubiologie + Nachhaltigkeit IBN, Building biology evaluation guidelines for sleeping areas. Supplement to the standard of building biology testing methods SBM-2015, https://buildingbiology.com/site/wp-content/uploads/richtwerte-2015-englisch.pdf, (2015) accessed July 5, 2019.
[29] Timothy Schoechle, Re-Inventing Wires: the Future of Landlines and Networks, National Institute for Science, Law & Public Policy, Washington, DC, 2018, p. 69 https://electromagnetichealth.org/wp-content/uploads/2018/05/Wires.pdf.
[30] C. Blackman, S. Forge, 5G Deployment: State of Play in Europe, USA and Asia, Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament, Luxembourg, (2019) http://www.europarl.europa.eu/RegData/etudes/IDAN/2019/631060/IPOL_IDA(2019)631060_EN.pdf.
[31] J. Bhatt, H.K. Verma, Design and development of wired building automation systems, Energy Build. 103 (2015) 396–413, https://doi.org/10.1016/j.enbuild.2015.02.054.
[32] J. Baliga, R. Ayre, K. Hinton, R. Tucker, Energy consumption in wired and wireless access networks, IEEE Commun. Mag. 49 (2011) 70–77, https://doi.org/10.1109/MCOM.2011.5783987.
[33] P. Lidström, J. Tierney, B. Wathey, J. Westman, Microwave assisted organic synthesis—a review, Tetrahedron 57 (2001) 9225–9283, https://doi.org/10.1016/S0040-4020(01)00906-1.
[34] Current Microwave Chemistry, n.d https://benthamscience.com/journals/current-microwave-chemistry/ accessed February 7, 2019.
[35] R. Ahirwar, S. Tanwar, U. Bora, P. Nahar, Microwave non-thermal effect reduces ELISA timing to less than 5 minutes, RSC Adv. 6 (2016) 20850–20857, https://doi.org/10.1039/C5RA27261K.
[36] R. Baan, Y. Grosse, B. Lauby-Secretan, F. El Ghissassi, V. Bouvard, L. Benbrahim-Tallaa, N. Guha, F. Islami, L. Galichet, K. Straif, WHO international agency for research on cancer monograph working group, carcinogenicity of radiofrequency electromagnetic fields, Lancet Oncol. 12 (2011) 624–626, https://doi.org/10.1016/S1470-2045(11)70147-4.
[37] International Agency for Research on Cancer (IARC), Working group on the evaluation of carcinogenic risks to humans, non-ionizing radiation, Part 2: radiofrequency electromagnetic fields, IARC Monogr. Eval. Carcinog. Risks Hum. 102

(2013) 1–460 https://monographs.iarc.fr/wp-content/uploads/2018/06/mono102.pdf.
[38] M.M. Marques, A. Berrington de Gonzalez, F.A. Beland, P. Browne, P.A. Demers, D.W. Lachenmeier, T. Bahadori, D.K. Barupal, F. Belpoggi, P. Comba, M. Dai, R.D. Daniels, C. Ferreccio, O.A. Grigoriev, Y.-C. Hong, R.N. Hoover, J. Kanno, M. Kogevinas, G. Lasfargues, R. Malekzadeh, S. Masten, R. Newton, T. Norat, J.J. Pappas, C. Queiroz Moreira, T. Rodríguez, J. Rodríguez-Guzmán, V. Sewram, L. Zeise, L. Benbrahim-Tallaa, V. Bouvard, I.A. Cree, F. El Ghissassi, J. Girschik, Y. Grosse, A.L. Hall, M.C. Turner, K. Straif, M. Korenjak, V. McCormack, K. Müller, J. Schüz, J. Zavadil, M.K. Schubauer-Berigan, K.Z. Guyton, Advisory group recommendations on priorities for the IARC monographs, Lancet Oncol. (2019), https://doi.org/10.1016/S1470-2045(19)30246-3 S1470204519302463.
[39] A.B. Miller, L.L. Morgan, I. Udasin, D.L. Davis, Cancer epidemiology update, following the 2011 IARC evaluation of radiofrequency electromagnetic fields (Monograph 102), Environ. Res. 167 (2018) 673–683, https://doi.org/10.1016/j.envres.2018.06.043.
[40] L. Hardell, M. Carlberg, Comments on the US National Toxicology Program technical reports on toxicology and carcinogenesis study in rats exposed to whole-body radiofrequency radiation at 900 MHz and in mice exposed to whole-body radiofrequency radiation at 1,900 MHz, Int. J. Oncol. (2018), https://doi.org/10.3892/ijo.2018.4606.
[41] G. Coureau, G. Bouvier, P. Lebailly, P. Fabbro-Peray, A. Gruber, K. Leffondre, J.-S. Guillamo, H. Loiseau, S. Mathoulin-Pélissier, R. Salamon, I. Baldi, Mobile phone use and brain tumours in the CERENAT case-control study, Occup. Environ. Med. 71 (2014) 514–522, https://doi.org/10.1136/oemed-2013-101754.
[42] L. Hardell, M. Carlberg, Mobile phone and cordless phone use and the risk for glioma – analysis of pooled case-control studies in Sweden, 1997–2003 and 2007–2009, Pathophysiology 22 (2015) 1–13, https://doi.org/10.1016/j.pathophys.2014.10.001.
[43] M. Peleg, O. Nativ, E.D. Richter, Radio frequency radiation-related cancer: assessing causation in the occupational/military setting, Environ. Res. 163 (2018) 123–133, https://doi.org/10.1016/j.envres.2018.01.003.
[44] J.G. West, N.S. Kapoor, S.-Y. Liao, J.W. Chen, L. Bailey, R.A. Nagourney, Multifocal breast cancer in young women with prolonged contact between their breasts and their cellular phones, Case Rep. Med. (2013) 1–5, https://doi.org/10.1155/2013/354682 2013.
[45] F. Momoli, J. Siemiatycki, M.L. McBride, M.-É. Parent, L. Richardson, D. Bedard, R. Platt, M. Vrijheid, E. Cardis, D. Krewski, Probabilistic multiple-bias modeling applied to the Canadian data from the interphone study of mobile phone use and risk of glioma, meningioma, acoustic neuroma, and parotid gland tumors, Am. J. Epidemiol. 186 (2017) 885–893, https://doi.org/10.1093/aje/kwx157.
[46] H.R. Gittleman, Q.T. Ostrom, C.D. Rouse, J.A. Dowling, P.M. de Blank, C.A. Kruchko, J.B. Elder, S.S. Rosenfeld, W.R. Selman, A.E. Sloan, J.S. Barnholtz-Sloan, Trends in central nervous system tumor incidence relative to other common cancers in adults, adolescents, and children in the United States, 2000 to 2010, Cancer 121 (2015) 102–112, https://doi.org/10.1002/cncr.29015.
[47] Q.T. Ostrom, H. Gittleman, P.M. de Blank, J.L. Finlay, J.G. Gurney, R. McKean-Cowdin, D.S. Stearns, J.E. Wolff, M. Liu, Y. Wolinsky, C. Kruchko, J.S. Barnholtz-Sloan, American brain tumor association adolescent and young adult primary brain and central nervous system tumors diagnosed in the United States in 2008-2012, Neuro Oncol. 18 (2016) i1–i50, https://doi.org/10.1093/neuonc/nov297.
[48] National Toxicology Program, National Institute of Environmental Sciences, Toxicology and carcinogenesis studies in Hsd: Sprague Dawley SD rats exposed to whole-body radio frequency radiation at a frequency (900 MHz) and modulations (GSM and CDMA) used by cell phones, NTP Tech. Rep. 595 (2018) 384 https://ntp.niehs.nih.gov/ntp/htdocs/lt_rpts/tr595_508.pdf?utm_source=direct&utm_medium=prod&utm_campaign=ntpgolinks&utm_term=tr595.
[49] L. Falcioni, L. Bua, E. Tibaldi, M. Lauriola, L. De Angelis, F. Gnudi, D. Mandrioli, M. Manservigi, F. Manservisi, I. Manzoli, I. Menghetti, R. Montella, S. Panzacchi, D. Sgargi, V. Strollo, A. Vornoli, F. Belpoggi, Report of Final Results Regarding Brain and Heart Tumors in Sprague-Dawley Rats Exposed from Prenatal Life until Natural Death to Mobile Phone Radiofrequency Field Representative of a 1.8 GHz GSM Base Station Environmental Emission, Environmental Research, 2018, https://doi.org/10.1016/j.envres.2018.01.037.
[50] A. Lerchl, M. Klose, K. Grote, A.F.X. Wilhelm, O. Spathmann, T. Fiedler, J. Streckert, V. Hansen, M. Clemens, Tumor promotion by exposure to radiofrequency electromagnetic fields below exposure limits for humans, Biochem. Biophys. Res. Commun. 459 (2015) 585–590, https://doi.org/10.1016/j.bbrc.2015.02.151.
[51] T. Tillmann, H. Ernst, J. Streckert, Y. Zhou, F. Taugner, V. Hansen, C. Dasenbrock, Indication of cocarcinogenic potential of chronic UMTS-modulated radiofrequency exposure in an ethylnitrosourea mouse model, Int. J. Radiat. Biol. 86 (2010) 529–541, https://doi.org/10.3109/09553001003734501.
[52] M. Redmayne, O. Johansson, Radiofrequency exposure in young and old: different sensitivities in light of age-relevant natural differences, Rev. Environ. Health 30 (2015) 323–335, https://doi.org/10.1515/reveh-2015-0030.
[53] O.P. Gandhi, G. Lazzi, C.M. Furse, Electromagnetic absorption in the human head and neck for mobile telephones at 835 and 1900 MHz, IEEE Trans. Microw. Theory Tech. 44 (1996) 1884–1896 https://www.ncbi.nlm.nih.gov/pubmed/21999884.
[54] O.P. Gandhi, L.L. Morgan, A.A. de Salles, Y.-Y. Han, R.B. Herberman, D.L. Davis, Exposure limits: the underestimation of absorbed cell phone radiation, especially in children, Electromagn. Biol. Med. 31 (2012) 34–51, https://doi.org/10.3109/15368378.2011.622827.
[55] A. Christ, M.-C. Gosselin, M. Christopoulou, S. Kühn, N. Kuster, Age-dependent tissue-specific exposure of cell phone users, Phys. Med. Biol. 55 (2010) 1767–1783, https://doi.org/10.1088/0031-9155/55/7/001.
[56] B. Siervo, M.S. Morelli, L. Landini, V. Hartwig, Numerical evaluation of human exposure to WiMax patch antenna in tablet or laptop, Bioelectromagnetics 39 (2018) 414–422, https://doi.org/10.1002/bem.22128.
[57] J.B. Ferreira, Á.A.A. de Salles, C.E. Fernández-Rodriguez, SAR simulations of EMF exposure due to tablet operation close to the user's body, 2015 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC), 2015, pp. 1–5, , https://doi.org/10.1109/IMOC.2015.7369205.
[58] M.R.A. Qureshi, Y. Alfadhl, X. Chen, A. Peyman, M. Maslanyj, S. Mann, Assessment of exposure to radio frequency electromagnetic fields from smart utility meters in GB; part II) numerical assessment of induced SAR within the human body: exposure to Radio Frequency Electromagnetic Fields from Smart Meters, Bioelectromagnetics 39 (2018) 200–216, https://doi.org/10.1002/bem.22094.
[59] F.S. Mahmoudabadi, S. Ziaei, M. Firoozabadi, A. Kazemnejad, Use of mobile phone during pregnancy and the risk of spontaneous abortion, J. Environ. Health Sci. Eng. 13 (2015), https://doi.org/10.1186/s40201-015-0193-z.
[60] J. Han, Z. Cao, X. Liu, W. Zhang, S. Zhang, [Effect of early pregnancy electromagnetic field exposure on embryo growth ceasing], Wei Sheng Yan Jiu 39 (2010) 349–352 https://www.ncbi.nlm.nih.gov/pubmed/20568468.
[61] W. Sun, X. Shen, D. Lu, Y. Fu, D. Lu, H. Chiang, A 1.8-GHz radiofrequency radiation induces EGF receptor clustering and phosphorylation in cultured human amniotic (FL) cells, Int. J. Radiat. Biol. 88 (2012) 239–244, https://doi.org/10.3109/09553002.2011.634882.
[62] E. Tsarna, M. Reedijk, L.E. Birks, M. Guxens, F. Ballester, M. Ha, A. Jiménez-Zabala, L. Kheifets, A. Lertxundi, H. Lim, J. Olsen, L.G. Safont, M. Sudan, E. Cardis, M. Vrijheid, T. Vrijkotte, A. Huss, R. Vermeulen, Maternal cell phone use during pregnancy, pregnancy duration and fetal growth in four birth cohorts, Am. J. Epidemiol. (2019), https://doi.org/10.1093/aje/kwz092.
[63] L. Birks, M. Guxens, E. Papadopoulou, J. Alexander, F. Ballester, M. Estarlich, M. Gallastegi, M. Ha, M. Haugen, A. Huss, L. Kheifets, H. Lim, J. Olsen, L. Santa-Marina, M. Sudan, R. Vermeulen, T. Vrijkotte, E. Cardis, M. Vrijheid, Maternal cell phone use during pregnancy and child behavioral problems in five birth cohorts, Environ. Int. 104 (2017) 122–131, https://doi.org/10.1016/j.envint.2017.03.024.
[64] H.A. Divan, L. Kheifets, C. Obel, J. Olsen, Prenatal and postnatal exposure to cell phone use and behavioral problems in children, Epidemiology 19 (2008) 523–529, https://doi.org/10.1097/EDE.0b013e318175dd47.
[65] H.A. Divan, L. Kheifets, C. Obel, J. Olsen, Cell phone use and behavioural problems in young children, J. Epidemiol. Community Health 66 (2012) 524–529, https://doi.org/10.1136/jech.2010.115402.
[66] S. Jun, The reciprocal longitudinal relationships between mobile phone addiction and depressive symptoms among Korean adolescents, Comput. Hum. Behav. 58 (2016) 179–186.
[67] F. Zheng, P. Gao, M. He, M. Li, J. Tan, D. Chen, Z. Zhou, Z. Yu, L. Zhang, Association between mobile phone use and self-reported well-being in children: a questionnaire-based cross-sectional study in Chongqing, China, BMJ Open 5 (2015) e007302, , https://doi.org/10.1136/bmjopen-2014-007302.
[68] S.A. Geronikolou, A. Chamakou, A. Mantzou, G. Chrousos, C. Kanaka–Gantenbein, Frequent cellular phone use modifies hypothalamic-pituitary-adrenal axis response to a cellular phone call after mental stress in healthy children and adolescents: a pilot study, Sci. Total Environ. 536 (2015) 182–188, https://doi.org/10.1016/j.scitotenv.2015.07.052.
[69] M. Redmayne, E. Smith, M.J. Abramson, The relationship between adolescents' well-being and their wireless phone use: a cross-sectional study, Environ. Health 12 (2013) 90, https://doi.org/10.1186/1476-069X-12-90.
[70] M. Redmayne, C.L. Smith, G. Benke, R.J. Croft, A. Dalecki, C. Dimitriadis, J. Kaufman, S. Macleod, M.R. Sim, R. Wolfe, M.J. Abramson, Use of mobile and cordless phones and cognition in Australian primary school children: a prospective cohort study, Environ. Health 15 (2016), https://doi.org/10.1186/s12940-016-0116-1.
[71] C. Sage, E. Burgio, Electromagnetic fields, pulsed radiofrequency radiation, and epigenetics: how wireless technologies may affect childhood development, Child Dev. 89 (2018) 129–136, https://doi.org/10.1111/cdev.12824.
[72] T.S. Aldad, G. Gan, X.-B. Gao, H.S. Taylor, Fetal radiofrequency radiation exposure from 800-1900 mhz-rated cellular telephones affects neurodevelopment and behavior in mice, Sci. Rep. 2 (2012) 312, https://doi.org/10.1038/srep00312.
[73] Y.-H. Byun, M. Ha, H.-J. Kwon, Y.-C. Hong, J.-H. Leem, J. Sakong, S.Y. Kim, C.G. Lee, D. Kang, H.-D. Choi, N. Kim, Mobile phone use, blood lead levels, and attention Deficit hyperactivity symptoms in children: a longitudinal study, PLoS One 8 (2013) e59742, https://doi.org/10.1371/journal.pone.0059742.
[74] R.N. Kostoff, C.G.Y. Lau, Combined biological and health effects of electromagnetic fields and other agents in the published literature, Technol. Forecast. Soc. Chang. 80 (2013) 1331–1349.
[75] J.A. Adams, T.S. Galloway, D. Mondal, S.C. Esteves, F. Mathews, Effect of mobile telephones on sperm quality: a systematic review and meta-analysis, Environ. Int. 70 (2014) 106–112, https://doi.org/10.1016/j.envint.2014.04.015.
[76] B.J. Houston, B. Nixon, B.V. King, G.N. De Iuliis, R.J. Aitken, The effects of radiofrequency electromagnetic radiation on sperm function, Reproduction 152 (2016) R263–R276, https://doi.org/10.1530/REP-16-0126.
[77] K. Liu, Y. Li, G. Zhang, J. Liu, J. Cao, L. Ao, S. Zhang, Association between mobile phone use and semen quality: a systemic review and meta-analysis, Andrology 2 (2014) 491–501, https://doi.org/10.1111/j.2047-2927.2014.00205.x.
[78] S. Dasdag, M. Taş, M.Z. Akdag, K. Yegin, Effect of long-term exposure of 2.4 GHz radiofrequency radiation emitted from Wi-Fi equipment on testes functions, Electromagn. Biol. Med. 34 (2015) 37–42, https://doi.org/10.3109/15368378.2013.869752.
[79] E. Odacı, H. Hancı, E. Yuluğ, S. Türedi, Y. Aliyazıcıoğlu, H. Kaya, S. Çolakoğlu,

Effects of prenatal exposure to a 900 MHz electromagnetic field on 60-day-old rat testis and epididymal sperm quality, Biotech. Histochem. 91 (2016) 9–19, https://doi.org/10.3109/10520295.2015.1060356.
[80] L. Hardell, T. Koppel, M. Carlberg, M. Ahonen, L. Hedendahl, Radiofrequency radiation at Stockholm Central Railway Station in Sweden and some medical aspects on public exposure to RF fields, Int. J. Oncol. 49 (2016) 1315–1324.
[81] L.K. Hedendahl, M. Carlberg, T. Koppel, L. Hardell, Measurements of radiofrequency radiation with a body-borne exposimeter in Swedish schools with Wi-Fi, Front. Public Health 5 (2017), https://doi.org/10.3389/fpubh.2017.00279.
[82] M.L. Pall, Wi-Fi is an important threat to human health, Environ. Res. 164 (2018) 405–416, https://doi.org/10.1016/j.envres.2018.01.035.
[83] L. Hardell, M. Carlberg, T. Koppel, L. Hedendahl, High radiofrequency radiation at Stockholm old town: an exposimeter study including the Royal Castle, Supreme court, three major squares and the Swedish parliament, Mol. Clin. Oncol. 6 (2017) 462–476, https://doi.org/10.3892/mco.2017.1180.
[84] J.F.B. Bolte, M. Maslanyj, D. Addison, T. Mee, J. Kamer, L. Colussi, Do car-mounted mobile measurements used for radio-frequency spectrum regulation have an application for exposure assessments in epidemiological studies? Environ. Int. 86 (2016) 75–83, https://doi.org/10.1016/j.envint.2015.09.024.
[85] G. Dürrenberger, J. Fröhlich, M. Röösli, M.-O. Mattsson, EMF monitoring—concepts, activities, gaps and options, Int. J. Environ. Res. Public Health 11 (2014) 9460–9479, https://doi.org/10.3390/ijerph110909460.
[86] A.L. Martens, J.F.B. Bolte, J. Beekhuizen, H. Kromhout, T. Smid, R.C.H. Vermeulen, Validity of at home model predictions as a proxy for personal exposure to radiofrequency electromagnetic fields from mobile phone base stations, Environ. Res. 142 (2015) 221–226, https://doi.org/10.1016/j.envres.2015.06.029.
[87] E. Chiaramello, M. Bonato, S. Fiocchi, G. Tognola, M. Parazzini, P. Ravazzani, J. Wiart, Radio frequency electromagnetic fields exposure assessment in indoor environments: a review, Int. J. Environ. Res. Public Health 16 (2019) 955, https://doi.org/10.3390/ijerph16060955.
[88] S. Sagar, S. Dongus, A. Schoeni, K. Roser, M. Eeftens, B. Struchen, M. Foerster, N. Meier, S. Adem, M. Röösli, Radiofrequency electromagnetic field exposure in everyday microenvironments in Europe: a systematic literature review, J. Expo. Sci. Environ. Epidemiol. 28 (2018) 147–160, https://doi.org/10.1038/jes.2017.13.
[89] K. Buchner, H. Eger, Changes of clinically important neurotransmitters under the influence of modulated RF fields—a long-term study under real-life conditions, Umwelt-Medizin-Gesellschaft 24 (2011) 44–57 https://www.avaate.org/IMG/pdf/Rimbach-Study-20112.pdf.
[90] M. Taheri, S.M.J. Mortazavi, M. Moradi, S. Mansouri, G.R. Hatam, F. Nouri, Evaluation of the effect of radiofrequency radiation emitted from Wi-Fi router and mobile phone simulator on the antibacterial susceptibility of pathogenic bacteria Listeria monocytogenes and Escherichia coli, Dose Response 15 (2017), https://doi.org/10.1177/1559325816688527 1559325816688527.
[91] R.T. Zoeller, L.N. Vandenberg, Assessing dose–response relationships for endocrine disrupting chemicals (EDCs): a focus on non-monotonicity, Environ. Health 14 (2015) 42, https://doi.org/10.1186/s12940-015-0029-4.
[92] R.T. Zoeller, Å. Bergman, G. Becher, P. Bjerregaard, R. Bornman, I. Brandt, T. Iguchi, S. Jobling, K.A. Kidd, A. Kortenkamp, N.E. Skakkebaek, J. Toppari, L.N. Vandenberg, A path forward in the debate over health impacts of endocrine disrupting chemicals, Environ. Health 13 (2014) 118, https://doi.org/10.1186/1476-069X-13-118.
[93] S.J. Genuis, C.T. Lipp, Electromagnetic hypersensitivity: fact or fiction? Sci. Total Environ. 414 (2012) 103–112, https://doi.org/10.1016/j.scitotenv.2011.11.008.
[94] O. Johansson, M. Hilliges, V. Björnhagen, K. Hall, Skin changes in patients claiming to suffer from “screen dermatitis”: a two-case open-field provocation study, Exp. Dermatol. 3 (1994) 234–238.
[95] D.O. Carpenter, The microwave syndrome or electro-hypersensitivity: historical background, Rev. Environ. Health 30 (2015) 217–222, https://doi.org/10.1515/reveh-2015-0016.
[96] L. Hedendahl, M. Carlberg, L. Hardell, Electromagnetic hypersensitivity-an increasing challenge to the medical profession, Rev. Environ. Health 30 (2015) 209–215, https://doi.org/10.1515/reveh-2015-0012.
[97] M.E. Sears, The Medical Perspective on Environmental Sensitivities, Canadian Human Rights Commission, Ottawa, Canada, 2007http://www.chrc-ccdp.gc.ca/sites/default/files/envsensitivity_en.pdf accessed January 17, 2019.
[98] S. Eltiti, D. Wallace, K. Zougkou, R. Russo, S. Joseph, P. Rasor, E. Fox, Development and evaluation of the electromagnetic hypersensitivity questionnaire, Bioelectromagnetics 28 (2007) 137–151, https://doi.org/10.1002/bem.20279.
[99] O. Johansson, Aspects of studies on the functional impairment electro-hypersensitivity, IOP Conf. Ser. Earth Environ. Sci. 10 (2010) 012005, https://doi.org/10.1088/1755-1315/10/1/012005.
[100] P. Levallois, R. Neutra, G. Lee, L. Hristova, Study of self-reported hypersensitivity to electromagnetic fields in California, Environ. Health Perspect. 110 (2002) 619–623.
[101] M.-C. Tseng M, Y.-P. Lin, T.-J. Cheng, Prevalence and psychiatric comorbidity of self-reported electromagnetic field sensitivity in Taiwan: a population-based study, J. Formos. Med. Assoc. 110 (2011) 634–641, https://doi.org/10.1016/j.jfma.2011.08.005.
[102] M. Dieudonné, Does electromagnetic hypersensitivity originate from nocebo responses? Indications from a qualitative study, Bioelectromagnetics 37 (2016) 14–24, https://doi.org/10.1002/bem.21937.
[103] M. Dieudonné, Becoming electro-hypersensitive: a replication study, Bioelectromagnetics 40 (2019) 188–200, https://doi.org/10.1002/bem.22180.
[104] United States Access Board, Recommendations for accommodations, n.d https://www.access-board.gov/research/completed-research/indoor-environmental-quality/recommendations-for-accommodations accessed April 29, 2019.
[105] Canadian Human Rights Commission, Policy on Environmental Sensitivities. Reviewed 2014., Canadian human Rights commission, https://www.chrc-ccdp.gc.ca/sites/default/files/policy_sensitivity_0.pdf, (2007) accessed January 17, 2019.
[106] C. Sage, D.O. Carpenter, Public health implications of wireless technologies, Pathophysiology 16 (2009) 233–246, https://doi.org/10.1016/j.pathophys.2009.01.011.
[107] C.L. Russell, 5 G wireless telecommunications expansion: public health and environmental implications, Environ. Res. 165 (2018) 484–495, https://doi.org/10.1016/j.envres.2018.01.016.
[108] A.A. Rooney, A.L. Boyles, M.S. Wolfe, J.R. Bucher, K.A. Thayer, Systematic Review and Evidence Integration for Literature-Based Environmental Health Science Assessments, Environmental Health Perspectives, 2014, https://doi.org/10.1289/ehp.1307972.
[109] L. Hardell, World Health Organization, radiofrequency radiation and health - a hard nut to crack (Review), Int. J. Oncol. 51 (2017) 405–413.
[110] G. Domenech-Pascual, Not Entirely Reliable: Private Scientific Organizations and Risk Regulation – the Case of Electromagnetic Fields, Social Science Research Network, Rochester, NY, 2013https://papers.ssrn.com/abstract=2902287 accessed November 20, 2018.
[111] D. Maisch, Conflict of interest and bias in health advisory committees: a case study of the WHO's EMF task group, ACNEM J. 21 (2006) 15–17 https://www.scribd.com/document/18363599/Conflict-of-Interest-Bias-in-Health-Advisory-Committees-A-case-study-of-the-WHO-s-Electromagnetic-Field-EMF-Task-Group.
[112] M.J. Maisch, Don, Spin in the Antipodes: a history of industry involvement in telecommunications health research in Australia (Updated), in: M.J. Walker (Ed.), Chapter 16. Corporate Ties that Bind: an Examination of Corporate Manipulation and Vested Interest in Public Health, Skyhorse Publishing, 2017, p. 28 https://www.emfacts.com/download/Chap_16_updated_to_Aug_2018.pdf.
[113] M.L. Pall, Scientific evidence contradicts findings and assumptions of Canadian Safety Panel 6: microwaves act through voltage-gated calcium channel activation to induce biological impacts at non-thermal levels, supporting a paradigm shift for microwave/lower frequency electromagnetic field action, Rev. Environ. Health 30 (2015) 99–116, https://doi.org/10.1515/reveh-2015-0001.
[114] P.C. Webster, Federal Wi-Fi panel criticized for undisclosed conflict, CMAJ (Can. Med. Assoc. J.) 185 (2013) E515–E516, https://doi.org/10.1503/cmaj.109-4523.
[115] P.C. Webster, Federal Wi-Fi safety report is deeply flawed, say experts, CMAJ (Can. Med. Assoc. J.) 186 (2014) E300, https://doi.org/10.1503/cmaj.109-4785.
[116] C. Sage, D. Carpenter, L. Hardell, Comment on SCENIHR: opinion on potential health effects of exposure to electromagnetic fields, bioelectromagnetics, Bioelectromagnetics 36 (2015) 480–484, https://doi.org/10.1002/bem.21949 2015.
[117] S.J. Starkey, Inaccurate official assessment of radiofrequency safety by the advisory group on non-ionising radiation, Rev. Environ. Health 31 (2016) 493–503, https://doi.org/10.1515/reveh-2016-0060.
[118] Norm Alster, Captured agency: how the federal communications industry is Dominated by the industries it presumably regulates, https://ethics.harvard.edu/files/center-for-ethics/files/capturedagency_alster.pdf, (2015) accessed March 13, 2019.
[119] A. Huss, M. Egger, M. Egger, K. Hug, K. Huwiler-Müntener, M. Röösli, D. Gomes, M.A. Da Ros, Source of funding and results of studies of health effects of mobile phone use: systematic review of experimental studies, Ciência Saúde Coletiva 13 (2008) 1005–1012.
[120] Nierop van, E. Lotte, Martin Roosli, Egger, Huss Mathias, Anke, Source of Funding in Experimental Studies of Mobile Phone Use on Health: Update of Systematic Review, C. R. Physique., 2010, pp. 622–627 https://www.sciencedirect.com/science/article/abs/pii/S1631070510001465.
[121] M. Prasad, P. Kathuria, P. Nair, A. Kumar, K. Prasad, Mobile phone use and risk of brain tumours: a systematic review of association between study quality, source of funding, and research outcomes, Neurol. Sci. (2017), https://doi.org/10.1007/s10072-017-2850-8.
[122] Z.R. Glaser, Bibliography of Reported Biological Phenomena (Effects) and Clinical Manifestations Attributed to Microwave and Radio-Frequency Radiation, June 1971 Naval Medical Research Institute Research Report, 1971, p. 106.
[123] S. Cucurachi, W.L.M. Tamis, M.G. Vijver, W.J.G.M. Peijnenburg, J.F.B. Bolte, G.R. de Snoo, A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF), Environ. Int. 51 (2013) 116–140, https://doi.org/10.1016/j.envint.2012.10.009.
[124] K.J. Fernie, D.M. Bird, R.D. Dawson, P.C. Laguë, Effects of electromagnetic fields on the reproductive success of American kestrels, Physiol. Biochem. Zool. 73 (2000) 60–65, https://doi.org/10.1086/316726.
[125] V. Shende, K. Patil, Electromagnetic radiations: a possible impact on population of house sparrow (Passer domesticus), Eng. Int. 3 (2015) 45–52, https://doi.org/10.18034/ei.v3i1.766.
[126] C. Waldmann-Selsam, A. Balmori-de la Puente, H. Breunig, A. Balmori, Radiofrequency radiation injures trees around mobile phone base stations, Sci. Total Environ. 572 (2016) 554–569, https://doi.org/10.1016/j.scitotenv.2016.08.045.
[127] H. Cadiou, P.A. McNaughton, Avian magnetite-based magnetoreception: a physiologist's perspective, J. R. Soc. Interface 7 (Suppl 2) (2010) S193–S205, https://doi.org/10.1098/rsif.2009.0423.focus.
[128] J.L. Kirschvink, J.L. Gould, Biogenic magnetite as a basis for magnetic field detection in animals, Biosystems 13 (1981) 181–201.
[129] T. Ritz, P. Thalau, J.B. Phillips, R. Wiltschko, W. Wiltschko, Resonance effects

indicate a radical-pair mechanism for avian magnetic compass, Nature 429 (2004) 177–180, https://doi.org/10.1038/nature02534.
[130] R. Wiltschko, W. Wiltschko, Sensing magnetic directions in birds: radical pair processes involving cryptochrome, Biosensors 4 (2014) 221–242, https://doi.org/10.3390/bios4030221.
[131] R. Wiltschko, P. Thalau, D. Gehring, C. Nießner, T. Ritz, W. Wiltschko, Magnetoreception in birds: the effect of radio-frequency fields, J. R. Soc. Interface 12 (2015), https://doi.org/10.1098/rsif.2014.1103.
[132] N. Keary, T. Ruploh, J. Voss, P. Thalau, R. Wiltschko, W. Wiltschko, H.-J. Bischof, Oscillating magnetic field disrupts magnetic orientation in Zebra finches, Taeniopygia guttata, Front. Zool. 6 (2009) 25, https://doi.org/10.1186/1742-9994-6-25.
[133] S. Engels, N.-L. Schneider, N. Lefeldt, C.M. Hein, M. Zapka, A. Michalik, D. Elbers, A. Kittel, P.J. Hore, H. Mouritsen, Anthropogenic electromagnetic noise disrupts magnetic compass orientation in a migratory bird, Nature 509 (2014) 353–356, https://doi.org/10.1038/nature13290.
[134] A. Pakhomov, J. Bojarinova, R. Cherbunin, R. Chetverikova, P.S. Grigoryev, K. Kavokin, D. Kobylkov, R. Lubkovskaja, N. Chernetsov, Very weak oscillating magnetic field disrupts the magnetic compass of songbird migrants, J. R. Soc. Interface 14 (2017), https://doi.org/10.1098/rsif.2017.0364.
[135] S. Schwarze, N.-L. Schneider, T. Reichl, D. Dreyer, N. Lefeldt, S. Engels, N. Baker, P.J. Hore, H. Mouritsen, Weak broadband electromagnetic fields are more disruptive to magnetic compass orientation in a night-migratory songbird (Erithacus rubecula) than strong narrow-band fields, Front. Behav. Neurosci. 10 (2016) 55, https://doi.org/10.3389/fnbeh.2016.00055.
[136] M. Desoli, P. Gillis, Y. Gossuin, Q.A. Pankhurst, D. Hautot, Definitive identification of magnetite nanoparticles in the abdomen of the honeybee Apis melifera, J. Phys. Conf. Ser. 17 (2005) 45–49 https://iopscience.iop.org/article/10.1088/1742-6596/17/1/007.
[137] D. Favre, Disturbing honeybees' behavior with electromagnetic waves: a methodology, J. Behav. 2 (2017) 5.
[138] V. Lambinet, M.E. Hayden, K. Reigl, S. Gomis, G. Gries, Linking magnetite in the abdomen of honey bees to a magnetoreceptive function, Proc. Biol. Sci. 284 (2017), https://doi.org/10.1098/rspb.2016.2873.
[139] C.-H. Liang, C.-L. Chuang, J.-A. Jiang, E.-C. Yang, Magnetic sensing through the abdomen of the honey bee, Sci. Rep. 6 (2016) 23657, https://doi.org/10.1038/srep23657.
[140] V.P. Sharma, N.R. Kumar, Changes in honeybee behaviour and biology under the influence of cellphone radiations, Curr. Sci. 98 (2010) 1376–1378 https://www.researchgate.net/publication/225187745_Changes_in_honey_bee_behaviour_and_biology_under_the_influence_of_cell_phone_radiations.
[141] Expert Committee, Ministry of Environment and Forest. India, Report on Possible Impacts of Communication Towers on Wildlife Including Birds and Bees, India Environmental Portal, 201188 pages http://www.indiaenvironmentportal.org.in/files/file/final_mobile_towers_report.pdf accessed January 18, 2019.
[142] M.-C. Cammaerts, Is electromagnetism one of the causes of the CCD? A work plan for testing this hypothesis, J. Behav. 2 (2017) 1006.
[143] M.-C. Cammaerts, G.A.E. Vandenbosch, V. Volski, Effect of short-term GSM radiation at representative levels in society on a biological model: the ant myrmica sabuleti, J. Insect Behav. 27 (2014) 514–526, https://doi.org/10.1007/s10905-014-9446-4.
[144] K. Darney, A. Giraudin, R. Joseph, P. Abadie, P. Aupinel, A. Decourtye, E. Le Bourg, M. Gauthier, Effect of high-frequency radiations on survival of the honeybee (Apis mellifera L.), Apidologie 47 (2016) 703–710, https://doi.org/10.1007/s13592-015-0421-7.
[145] A. Lázaro, A. Chroni, T. Tscheulin, J. Devalez, C. Matsoukas, T. Petanidou, Electromagnetic radiation of mobile telecommunication antennas affects the abundance and composition of wild pollinators, J. Insect Conserv. 20 (2016) 315–324, https://doi.org/10.1007/s10841-016-9868-8.
[146] Grish Kumar, Report on Cell Tower Radiation Submitted to Secretary, DOT, Delhi, India, 2010https://www.ee.iitb.ac.in/~mwave/GK-cell-tower-rad-report-DOT-Dec2010.pdf accessed January 18, 2019.
[147] A. Balmori, Possible effects of electromagnetic fields from phone masts on a population of white stork (Ciconia ciconia), Electromagn. Biol. Med. 24 (2005) 109–119, https://doi.org/10.1080/15368370500205472.
[148] A. Balmori, Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation, Sci. Total Environ. 518–519 (2015) 58–60, https://doi.org/10.1016/j.scitotenv.2015.02.077.
[149] A. Balmori, Ö. Hallberg, The urban decline of the house sparrow (Passer domesticus): a possible link with electromagnetic radiation, Electromagn. Biol. Med. 26 (2007) 141–151, https://doi.org/10.1080/15368370701410558.
[150] B.B. Levitt, H. Lai, Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays, Environ. Rev. 18 (2010) 369–395, https://doi.org/10.1139/a10-018.
[151] D.J. Panagopoulos, Electromagnetic interaction between environmental fields and living systems determines health and well-being, Electromagnetic Fields: Principles Biophysical Effects, Nova Science Publishers, 2013, https://www.researchgate.net/publication/286168695_Electromagnetic_interaction_between_environmental_fields_and_living_systems_determines_health_and_well-being.
[152] S. Sivani, D. Sudarsanam, Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem – a review, Biol. Med. 4 (2012) 202–216.
[153] R.W. Geisel, Insurers Exclude Risks Associated with Electromagnetic Radiation, Business Insurance, 2007, http://www.businessinsurance.com/article/20070603/STORY/100022051/Insurers-exclude-risks-associated-with-electromagnetic-radiation accessed January 11, 2019.
[154] Sandra Burmeier, Reto Schneider, Philippe Brahin, Swiss Re SONAR – new emerging risk insights, https://media.swissre.com/documents/SONAR_2014.pdf, (2014) accessed January 10, 2019.
[155] RE Institute Swiss, SONAR 2019: new emerging risk insights, https://www.swissre.com/institute/research/sonar/sonar2019.html, (2019) accessed July 3, 2019.
[156] Trevor Maynard, Neil Smith, Jennie Kent, Lloyd's Emerging Risks team report. Electro-magnetic fields: recent developments, Retrived from https://www.smombiegate.org/wp-content/uploads/2019/02/smombie-gate-EMF-Final-November-2010.pdf, (2010) accessed January 10, 2019.
[157] M.O.R.I. Ipsos, The 2013 Lloyd's risk Index, https://www.ipsos.com/sites/default/files/publication/1970-01/loyalty-lloyds-risk-index-2013-report.pdf, (2013) accessed February 16, 2019.
[158] CompleteMarkets, Electromagnetic Fields (Utilities) Liability Insurance, Electromagnetic Fields (Utilities) Liability, https://completemarkets.com/Electromagnetic-Fields-Utilities-Liability-Insurance/Storefronts/ accessed January 17, 2019.
[159] AT&T, Terms of Service - Legal policy center - AT&T, https://www.att.com/legal/terms.mobileInsurance.html, (2018) accessed January 29, 2019.
[160] Peter A. Halprin, Risk Management – the broadening scope of pollution legal liability insurance, http://www.rmmagazine.com/2015/08/25/the-broadening-scope-of-pollution-legal-liability-insurance/, (2015) accessed January 10, 2019.
[161] John Wasilchuk, Mathew Pateidi, Understanding environmental exposure risks: contractor's pollution liability, construction executive, https://constructionexec.com/article/understanding-environmental-exposure-risks-contractors-pollution-liability, (2017) accessed January 11, 2019.
[162] Hamid Molla-Djafari, Gernot Schmid, Helga Tuschl, Letizia Farmer, Georg Neubauer, Michael Kundi, Christopher Gerner, Wilhelm Mosgoller, ATHEM. Untersuchung Athermischer Wirkungen Elektromagnetischer Felder im Mobilfunkbereich. report, Band 47 [ATHEM. Investigation of the Athermal Effects of Electromagnetic Fields in the Mobile Radio Area]. Report 47, AUVA, 2011, https://www.auva.at/cdscontent/?contentid=10007.672634&portal=auvaportal&viewmode=content accessed January 17, 2019.
[163] Hamid Molla-Djafari, Klaus Schiessl, Gernot Schmid, Michael Kundi, Siegfried Knasmuller, Wilhelm Mosgoller, ATHEM-2 - Untersuchung Athermischer Wirkungen Elektromagnetischer Felder im Mobilfunkbereich. AUVA, 2016 Report 70 [ATHEM-2. Investigation of the Athermal Effects of Electromagnetic Fields in the Mobile Radio Area. Report 70] https://www.auva.at/cdscontent/?contentid=10007.769605&portal=auvaportal&viewmode=content accessed January 17, 2019.
[164] Crown Castle International, 2017 Annual Report and Form 10K, http://www.annualreports.com/Company/crown-castle-international, (2018) accessed January 20, 2019.
[165] Verizon, 2017 Annual Report. Giving people the ability to do more, https://www.verizon.com/about/investors/annual-report, (2016) accessed January 20, 2019.
[166] Locke Lord, Gregory T. Casamento, Sarah M. Chen, Robert W. Mouton, The status of cell phone as carcinogens litigations, Lexology, 2012, https://www.lexology.com/library/detail.aspx?g=3ea7aaa3-5d32-4278-bb0c-a0de1f9dd5ec accessed January 17, 2019.
[167] District of Columbia Court of Appeals, Murray et al. v Motorola, Superior Court Case No. 2001 CA 008479 B, Casewatch, https://www.casewatch.net/civil/motorola/petition.pdf, (2014) accessed January 17, 2019.
[168] Associated Press, Italian court finds link between cellphone use and tumor, https://www.courthousenews.com/italian-court-finds-link-cell-phone-use-tumor/, (2017) accessed February 1, 2019.
[169] McDonald, Comcare, http://www8.austlii.edu.au/cgi-bin/viewdoc/au/cases/cth/AATA/2013/105.html, (2013) accessed January 26, 2019.
[170] Tribunal Superior de Justica, Sala de lo Social. Madrid, Roj: STSJM 6895/2016-ECLI: ES TSJM:2016:6895. Id Cendoj: 28079340022016100509. No de Recurso: 327/2016. No de Resolucion: 588/2016 http://cemical.diba.cat/sentencies/fitxersSTSJ/STSJ_327_2016.pdf, (2016) accessed February 1, 2019.
[171] Repubblica Italiana In Nome Del Popolo Italiano, Il tribunale amministratrativo Regionale per il Lazio (Sezione terza Quater), Sito istituzionale della Giustizia amministrativa, n.d. http://www.salute.gov.it/portale/news/p3_2_4_1_1.jsp?lingua=italiano&menu=salastampa&p=comunicatistampa&id=5131 accessed January 31, 2019.
[172] M. Redmayne, International policy and advisory response regarding children's exposure to radio frequency electromagnetic fields (RF-EMF), Electromagn. Biol. Med. 35 (2016) 176–185, https://doi.org/10.3109/15368378.2015.1038832.
[173] Republique et Canton de Geneve, Procès-verbal de la session du Grand Conseil des 9 et 10 avril 2019, http://ge.ch/grandconseil/data/odj/020111/PV_AVRIL2019.pdf, (2019).
[174] Canton de Vaud [Vaud, Switzerland], [Minutes of the grand Council] Séance du Grand conseil, Decision No. 10, 2019. https://www.vd.ch/fileadmin/user_upload/organisation/gc/fichiers_pdf/2017-2022/Ordre_du_jour_du_GC_9avril19_PV.pdf.
[175] F. Fivaz, [Draft decree submitting an urgent cantonal initiative to the Federal Assembly for a moratorium on the installation of "5G" mobile networks] Projet de décret soumettantune initiative cantonale urgente à l'Assemblée fédérale pour un moratoire sur l'installation des réseaux mobiles « 5G », https://www.ne.ch/autorites/GC/objets/Documents/ProjetsLoisDecrets/2019/19133.pdf, (2019) accessed July 5, 2019.
[176] Le Service Public D'Acces au Droit en Polynesie Francaise, Texte adopté LP n° 201641 LP/APF du 08/12/2016 de la loi du pays tendant à protéger la population en matière d'exposition aux ondes électromagnétiques, http://lexpol.cloud.pf/LexpolAfficheTexte.php?texte=478012, (2016) accessed July 10, 2019.
[177] French National Assembly, Law proposition amended by the Senate, http://www.

assemblee-nationale.fr/14/pdf/propositions/pion2065.pdf, (2014) accessed January 18, 2019.
[178] Jeong-Ki Park, Sam-Young Chung, Hyung-Do Choi, National Report (Republic of Korea), World Health Organization -International EMF Project. 21st international advisory committee. Brussels, https://www.who.int/peh-emf/project/mapnatreps/korea-2016.pdf, (2016) accessed January 18, 2019.
[179] Federale Overheidsdienst Volksgezondheid, Veligheid Van De Voedselkten En Leefmilieu, New rules for selling mobile phones. Practical guide for sellers and distributors, https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/19096044/Guide%20mobile%20phone%20v5.pdf accessed January 18, 2019.
[180] Department of Telecommunications, Ministry of communication, government of India, a journey for EMF, http://dot.gov.in/journey-emf, (2017) accessed January 18, 2019.
[181] GSMA, Base station planning permission in Europe, public policy, https://www.gsma.com/publicpolicy/base-station-planning-permission-in-europe, (2013) accessed January 18, 2019.
[182] Government of France, Décret n° 2010-1207 du 12 octobre 2010 relatif à l'affichage du débit d'absorption spécifique des équipements terminaux radioélectriques [Decree No. 2010-1207 of October 12, 2010 relating to the display of the specific absorption rate of radio terminal equipment], LegiFrance, 2010, https://www.legifrance.gouv.fr/eli/decret/2016/8/3/ETST1611714D/jo accessed January 17, 2019.
[183] Medical Association of Athens, Workshop on the Need to Take Measures to Protect against Electromagnetic Radiation, Ιατρικός Σύλλογος Αθηνών, 2017, http://www.isathens.gr/syndikal/6743-imerida-ilektromagnitiki-aktinovolia.html accessed January 18, 2019.
[184] Government of France, Décret n° 2016-1074 du 3 août 2016 relatif à la protection des travailleurs contre les risques dus aux champs électromagnétiques [Décret n ° 2016-1074 of 3 August 2016 on the protection of workers against pollution caused by electromagnetic emissions], LegiFrance, 2016, https://www.legifrance.gouv.fr/eli/decret/2016/8/3/ETST1611714D/jo accessed January 18, 2019.
[185] American Academy of Pediatrics, Cell Phone Radiation & Children's Health, What Parents Need to Know, Healthy Children.Org., 2016, http://www.healthychildren.org/English/safety-prevention/all-around/Pages/Cell-Phone-Radiation-Childrens-Health.aspx accessed January 18, 2019.
[186] Cyprus National Committee on Environment and Children's Health, http://www.cyprus-child-environment.org/easyconsole.cfm/id/12/lang/en accessed January 18, 2019.
[187] STUK (Radiation and Nuclear Safety Authority in Finland), Exposure Can Be Reduced by Simple Means, STUK, 2015, https://www.stuk.fi/web/en/topics/mobile-telephones-and-base-stations/how-to-reduce-your-exposure accessed January 18, 2019.
[188] Parliamentary Assembly of the Council of Europe, Resolution 1815 (2011) - the potential dangers of electromagnetic fields and their effect on the environment, https://assembly.coe.int/nw/xml/XRef/Xref-XML2HTML-en.asp?fileid=17994, (2011) accessed January 18, 2019.
[189] Collaboration for High Performance Schools, US-CHPS Criteria. New construction and renovation, https://chps.net/us-chps-criteria, (2014) accessed January 18, 2019.
[190] Adrienne Markowitz, Eileen Senn, Minimize health risks from electronic devices, New Jersey Education Association, 2016, https://www.njea.org/minimize-health-risks-from-electronic-devices/ accessed January 18, 2019.
[191] Maryland Children's Environmental Health and Protection Advisory Council, Wi-fi radiation in schools in Maryland, https://phpa.health.maryland.gov/OEHFP/EH/Pages/WiFiCEHPAC.aspx, (2016) accessed January 18, 2019.
[192] J. Sinopoli, Smart Building Systems for Architects, Owners and Builders, Elsevier, 2010, https://doi.org/10.1016/C2009-0-20023-7.
[193] T. Koppel, M. Ahonen, The shielding of inbound radiofrequency electromagnetic fields at workplaces, Saf. Technog. Environ. 5 (2014) 29–37, https://doi.org/10.7250/ste.2014.003.
[194] Canadian Agency for Drugs and Technologies in Health (CADTH), Wireless device use and patient monitoring equipment in any healthcare delivery setting: a review of safety and guidelines, https://www.cadth.ca/wireless-device-use-and-patient-monitoring-equipment-any-healthcare-delivery-setting-review-safety-0, (2016) accessed July 6, 2019.
[195] Canadian Agency for Drugs and Technologies in Health (CADTH), Wireless and mobile device access for patients in healthcare settings: clinical benefit and evidence-based guidelines, n.d https://www.cadth.ca/wireless-and-mobile-device-access-patients-healthcare-settings-clinical-benefit-and-evidence-based accessed July 9, 2019.
[196] International Commissionon Non-Ionizing Radiation Protection (ICNIRP), ICNIRP - high frequency fields revision of the guidelines on highfrequency up to 300 GHz, http://www.icnirp.org/en/activities/work-plan/details/work-plan-hf.html, (2009) accessed January 12, 2017.
[197] World Health Organization, Global Health Observatory, Exposure limits for radiofrequency fields (public) - data by country, WHO, http://apps.who.int/gho/data/node.main.EMFLIMITSPUBLICRADIOFREQUENCY?lang=en, (2017) accessed July 3, 2019.
[198] H. Mazar, Human radio frequency exposure limits: an update of reference levels in Europe, USA, Canada, China, Japan and Korea, 2016 International Symposium on Electromagnetic Compatibility - EMC EUROPE, IEEE, Wroclaw, Poland, 2016, pp. 467–473, , https://doi.org/10.1109/EMCEurope.2016.7739164.
[199] Austrian Sustainable Building Council, Set of Criteria, n.d. https://www.oegnb.net/zertifikat.htm?typ=hs accessed February 16, 2019.
[200] S. Warren, P. Aebersold, W. Cohn, Health Physics & Nuclear Medicine After the Manhattan Project, Atomic Heritage Foundation, 2017, https://www.atomicheritage.org/history/health-physics-nuclear-medicine-after-manhattan-project accessed July 6, 2019.
[201] S. Singh, N. Kapoor, Health Implications of Electromagnetic Fields, Mechanisms of Action, and Research Needs, Adv. Biol. (2014), https://doi.org/10.1155/2014/198609.
[202] CDC, ALARA - As Low As Reasonably Achievable, Centers for Disease Control and Prevention, https://www.cdc.gov/nceh/radiation/alara.html, (2015) accessed July 6, 2019.
[203] D. Abdorahimi, A.M. Sadeghioon, Comparison of radio frequency path loss models in soil for wireless underground sensor networks, J. Sens. Actuator Netw. 8 (2019) 35, https://doi.org/10.3390/jsan8020035.
[204] International Telecommunication Union - Radiocommunication Sector, Effects of building materials and structures on radiowave propagation above about 100 MHz, https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2040-1-201507-I!!PDF-E.pdf, (2015) accessed June 27, 2019.
[205] P. Saville, Review of radar absorbing materials, defence research and development Canada, https://apps.dtic.mil/dtic/tr/fulltext/u2/a436262.pdf, (2005) accessed July 5, 2019.
[206] A.K. Singh, A. Shishkin, T. Koppel, N. Gupta, A review of porous lightweight composite materials for electromagnetic interference shielding, Compos. B Eng. 149 (2018) 188–197, https://doi.org/10.1016/j.compositesb.2018.05.027.
[207] V. Shukla, Review of electromagnetic interference shielding materials fabricated by iron ingredients, Nanoscale Adv. 1 (2019) 1640–1671, https://doi.org/10.1039/C9NA00108E.
[208] G.N. Vizi, G.A.E. Vandenbosch, Building materials and electromagnetic radiation: the role of material and shape, J. Build Eng. 5 (2016) 96–103, https://doi.org/10.1016/j.jobe.2015.11.010.
[209] W.C. Stone, Electromagnetic Signal Attenuation in Construction Materials, U.S. National Institute of Standards and Technology, Gaithersburg, Maryland, U.S.A., 1997.
[210] S. Wall, Z.-M. Wang, T. Kendig, D. Dobraca, M. Lipsett, Real-world cell phone radiofrequency electromagnetic field exposures, Environ. Res. 171 (2019) 581–592, https://doi.org/10.1016/j.envres.2018.09.015.
[211] T. Stimpson, L. Liu, J. Zhang, R. Hill, W. Liu, Y. Zhan, Assessment of security and vulnerability of home wireless networks, 2012 9th International Conference on Fuzzy Systems and Knowledge Discovery, 2012, pp. 2133–2137, , https://doi.org/10.1109/FSKD.2012.6233783.
[212] International Telecommunication Union - Telecommunication Standardization Sector, The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment, https://www.itu.int/rec/T-REC-K.Sup14-201805-I, (2018) accessed July 1, 2019.
[213] C. Törnevik, Ericsson Research, Stockholm, impact of EMF limits on 5G network roll-out, https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20171205/Documents/S3_Christer_Tornevik.pdf, (2017) accessed July 5, 2019.

ANNEX: EXAMPLES OF ACTIONS FOR REDUCING RFR EXPOSURE

1. Focus actions for reducing exposure to RFR on pregnant women, infants, children and adolescents, as well as males who might wish to become fathers.
2. Reduce, as much as possible, the extent to which infants and young children are exposed to RFR from Wi-Fi-enabled devices such as baby monitors, wearable devices, cell phones, tablets, etc.
3. Avoid placing cell towers and small cell antennae close to schools and homes pending further research and revision of the existing exposure limits. In schools, homes and the workplace, cable or optical fiber connections to the Internet are preferred. Wi-Fi routers in schools and daycares/kindergartens should be strongly discouraged and programs instituted to provide Internet access via cable or fiber.
4. Ensure that WTDs minimize radiation by transmitting only when necessary, and as infrequently as is feasible. Examples include transmitting only in response to a signal (e.g., accessing a router or querying a device, a cordless phone handset being turned on, or voice or motion activation). Prominent, visible power switches are needed to ensure that WTDs can be easily turned on only when needed, and off when not required (e.g., Wi-Fi when sleeping).
5. Lower permitted power densities in close proximity to fixed-site antennae, from "occupational" limits to exposure limits for the general public.
6. Update current exposure limits to be protective against the non-thermal effects of RFR. Such action should be taken by all heath ministries and public health agencies, as well as industry regulatory bodies. Exposure limits should be based on measurements of RFR levels related to biological effects (2).
7. Ensure that advisories relating to cell phone use are placed in such a way that purchasers can find them easily, similar to the Berkeley Cell Phone "Right to Know" Ordinance (86).
8. Advise the public that texting and speaker mode are preferable to holding cell phones to the ear. Alternatively, use hands-free accessories for cell phones, including air tube headsets that interrupt the transmission of RFR.
9. When possible, keep cell phones away from the body (e.g., on a nearby desk, in a purse or bag, or on a mounted hands-free accessory in motor vehicles).
10. Delay the widespread implementation of 5G (and any other new technology) until studies can be conducted to assess safety. This includes a wide range of household and community-wide infrastructure WTDs and self-driving vehicles, as well as the building of 5G minicells.
11. Fiber-optic connections for the Internet should be made available to every home, office, school, warehouse and factory, when and where possible.

GLOSSARY

ALARA	As Low a level As Reasonably Achievable
CBTRUS	Central Brain Tumor Registry of the United States
CI	Confidence Interval
EMR	Electro Magnetic Radiation
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
INEP	International Network for Epidemiology in Policy
LTE	Long-Term Evolution modulation
NTP	U.S. National Toxicology Program
OR	Odds Ratio
RFR	Radio-Frequency Radiation
SAR	Specific Absorption Rate
WTD	Wireless Transmitting Device

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Evidence for a health risk by RF on humans living around mobile phone base stations: From radiofrequency sickness to cancer

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ABSTRACT

The objective of this work was to perform a complete review of the existing scientific literature to update the knowledge on the effects of base station antennas on humans. Studies performed in real urban conditions, with mobile phone base stations situated close to apartments, were selected. Overall results of this review show three types of effects by base station antennas on the health of people: radiofrequency sickness (RS), cancer (C) and changes in biochemical parameters (CBP). Considering all the studies reviewed globally (n = 38), 73.6% (28/38) showed effects: 73.9% (17/23) for radiofrequency sickness, 76.9% (10/13) for cancer and 75.0% (6/8) for changes in biochemical parameters. Furthermore, studies that did not meet the strict conditions to be included in this review provided important supplementary evidence. The existence of similar effects from studies by different sources (but with RF of similar characteristics), such as radar, radio and television antennas, wireless smart meters and laboratory studies, reinforce the conclusions of this review. Of special importance are the studies performed on animals or trees near base station antennas that cannot be aware of their proximity and to which psychosomatic effects can never be attributed.

1. Introduction

During the last few decades, hundreds of thousands of mobile phone base stations and other types of wireless communications antennas have been installed around the world, in cities and in nature, including protected natural areas, in addition to pre-existing antennas (television, radio broadcasting, radar, etc.). Only the aesthetic aspects or urban regulations have been generally considered in this deployment, while the biological, environmental and health impacts of the associated non-ionizing electromagnetic radiation emissions have not been assessed so far. Therefore, the effects on humans living around these anthropogenic electromagnetic field sources (antennas) have not been considered.

In France, there is a significant contribution of mobile phone base stations in the exposure to radiofrequency electromagnetic fields (RF-EMF) of urban citizens living nearby (De Giudici et al., 2021). Some studies from India indicate that more than 15% of people have levels of EMF strength above 12 V/m due to their proximity to antennas (Premlal and Eldhose, 2017). Exposure estimates have shown that RF-EMF from mobile telephone systems is stronger in urban than in rural areas. For instance, in Sweden the levels of RF radiation have increased considerably in recent years, both outdoor and indoor, due to new telecommunication technologies, and the median power density measured for RF fields between 30 MHz and 3 GHz was 16 $\mu W/m^2$ in rural areas, 270 $\mu W/m^2$ in urban areas and 2400 $\mu W/m^2$ in city areas (Hardell et al., 2018). Total exposure varies not only between urban and rural areas but also, depending on residential characteristics, between different floors of a building, with a tendency for building exposure to increase at higher floors (Breckenkamp et al., 2012).

Over the past five decades, and more intensively since the beginning of this century, many studies and several reviews have been published on the effects of anthropogenic electromagnetic radiation on humans living around the antennas. The first studies were carried out with radio and television antennas, investigating increases in cancer and leukaemia (Milham, 1988; Maskarinec et al., 1994; Hocking et al., 1996; Dolk et al., 1997a, 1997b; Michelozzi et al., 1998; Altpeter et al., 2000), as well as around radars (Kolodynski and Kolodynska, 1996; Goldsmith, 1997).

Regarding base station antennas, there are scientific discrepancies in their effects: some studies concluded that there are no health-related effects (e.g. Augner and Hacker, 2009; Blettner et al., 2009; Röösli et al., 2010; Baliatsas et al., 2016) whereas others found increases in cancer and other health problems in humans living around antennas (e.g. Santini et al., 2002; Navarro et al., 2003; Bortkiewicz et al., 2004;

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0013-9351/© 2022 Elsevier Inc. All rights reserved.

Eger et al., 2004; Wolf and Wolf, 2004; Abdel-Rassoul et al., 2007; Khurana et al., 2010; Dode et al., 2011; Shinjyo and Shinjyo, 2014; Gandhi et al., 2015; López et al., 2021; Rodrigues et al., 2021). There is a specific symptomatology linked to radar and RF exposure at low levels, characterized by functional disturbances of the central nervous system (headache, sleep disturbance, discomfort, irritability, depression, memory loss, dizziness, fatigue, nausea, appetite loss, difficulty in concentration, dizziness, etc.), that has been termed 'RF sickness' (Lilienfeld et al., 1978; Johnson Lyakouris, 1998; Navarro et al., 2003).

The objective of this study was to perform a complete review of the existing scientific literature to update the knowledge on the effects of base stations on humans living around the antennas.

2. Methods

A search was performed in the EMF portal, Google Scholar and PubMed databases with the words: "mobile phone base station and health" or "cell tower and health".

Only studies performed in real urban conditions, with mobile phone base stations situated close to apartments, were selected. Studies conducted in larger regions with numerous antennas, based on surveys and geographic data, were also included.

On the contrary, studies were excluded that considered different sources of electromagnetic radiation, such as mobile phone base stations together with broadcast transmitters (TV and radio), radar, mobile phones, cordless phones, Wi-Fi or wireless smart meters. Also excluded were those that included antennas and powerlines jointly. Studies that only performed measurements or modelling of radiation levels in the environment of the antennas or in the body, but did not deal with health effects, were excluded, as were surveys on risk perception and the nocebo effect, modelled radiofrequency electromagnetic field exposure from mobile-phone base stations or perceived exposure. All experimental laboratory studies, experiments in an exposure chamber or adapted room were also excluded. Finally, the comments or criticism of previously published studies were also excluded. However, due to their importance the conclusions of some of the excluded studies will be discussed in the corresponding section.

3. Results

The studies that met the selected criteria are presented in chronological order in Table 1, catalogued as Y/N depending on whether or not they found effects. The selected studies cover three types of effects: radiofrequency sickness (RS) (according to Lilienfeld et al., 1978; Johnson Lyakouris, 1998), cancer (C) and changes in biochemical parameters (CBP). Table 1 also includes the authors, year and country, antenna type, study design, diseases and symptoms found/not found and the main conclusions of each study.

Considering all the selected studies (n = 38), 73.6% (28/38) showed effects: 73.9% (17/23) for radiofrequency sickness, 76.9% (10/13) for cancer and 75.0% (6/8) for changes in biochemical parameters (Fig. 1). Therefore, most of the studies carried by research groups from twenty different countries reach the same conclusions.

For the reasons previously explained, the following studies (n = 85) were not considered in this review, even though the conclusions of some of these studies will be discussed later due to their importance regarding the similarities of the electromagnetic radiation types involved and the health effects found in many cases. Several studies only performed measurements or modelling of radiation levels in the environment of the antennas or in the body, but did not deal with the effects on health (e.g. Aniołczyk, 1999; Henderson and Bangay, 2006; Keow and Radiman, 2006; Neitzke et al., 2007; Bürgi et al., 2008; Augner et al., 2009; Chen and Chuang, 2009; Schmiedel et al., 2009; Viel et al., 2009; Hansson et al., 2011; Alhekail et al., 2012; Breckenkamp et al., 2012; Beekhuizen et al., 2013; Bürgi et al., 2014; Lyare et al., 2019; Urbinello et al., 2014; Lemaire et al., 2016; Admawi, 2021; De Giudici et al., 2021; Kazaure et al., 2021; Yetiş and Kayili, 2021). Some were surveys on risk perception and the nocebo effect, modelled RF-EMF exposure from mobile-phone base stations or perceived exposure (Wiedemann et al., 2006; Dohle et al., 2012; Kowall et al., 2012; Freudenstein et al., 2015; Dieudonné, 2016; Klaps et al., 2016; Martens et al., 2017; Koh et al., 2020). Others jointly considered various sources of electromagnetic fields such as telephone antennas, mobile phones, cordless phones, Wi-Fi, powerlines or wireless smart meters (Seitz et al., 2005; Baliatsas et al., 2011; Atzmon et al., 2012; Eskander et al., 2012; Frei et al., 2012; Lamech, 2014; Singh and Pati, 2016; Boehmert et al., 2020; Akkam et al., 2020). Some studied the effects of radio or television antennas (Milham, 1988; Maskarinec et al., 1994; Hocking et al., 1996; Dolk et al., 1997a, 1997b; McKenzie et al., 1998; Michelozzi et al., 1998; Altpeter et al., 2000; Hocking and Gordon, 2000; Boscolo et al., 2001; Cooper et al., 2001; Michelozzi et al., 2002; Hallberg and Johansson, 2002; Elwood, 2003; Ha et al., 2003; Park et al., 2004; Abelin et al., 2005; Altpeter et al., 2006; Ha et al., 2007; Satta et al., 2018). Others were radar studies (Kolodynski and Kolodynska, 1996; Goldsmith, 1997; Szmigielski et al., 2001; Yakymenko et al., 2011; Schoeni et al., 2016; Martens et al., 2018). Some studies performed experiments in a laboratory, exposure chamber or adapted room, with simulated or real electromagnetic radiation from base station antennas (e.g. Zwamborn et al., 2003; Hinrichs et al., 2005; Regel et al., 2006, 2007; Eltiti et al., 2007; Leitgeb et al., 2008; Riddervold et al., 2008; Augner et al., 2009; Augner et al., 2010; Wallace et al., 2010; Danker-Hopfe et al., 2010; Falcioni et al., 2018; Azimzadeh and Jelodar, 2019; Smith-Roe et al., 2020). Some reports were comments or criticisms of previously published studies (e.g. Coggon, 2006; Röösli and Huss, 2008; Bithell, 2010; Dode and Leão, 2012; Foster and Trottier, 2012; Mortazavi, 2014, 2017).

4. Discussion

The results of this review show three types of effects by base station antennas on the health of humans: radiofrequency sickness, cancer and changes in biochemical parameters (Fig. 1). From among all these studies, most of them found effects (73.6%). Thus, despite some limitations and differences in study design, statistical measures, risk estimates and exposure categories (Khurana et al., 2010), together they provide a consistent view of the effects on the health of people living in the vicinity of base station antennas.

Studies conducted in large regions with numerous antennas, based on surveys and geographic data (e.g. Augner and Hacker, 2009; Dode et al., 2011; Baliatsas et al., 2016; Martens et al., 2017; Dode et al. al., 2021), have the limitation that there may be many factors other than the base station antennas affecting the health of the population (environmental and occupational determinants of diseases and symptoms, individual characteristics such as food and life habits, activity level, smoking, self-medication, individual pathologies or genetic factors) that can act as confounding factors. It is important to mention here that the meters used for power density measurements in research papers should have more high quality equipment and better measurement methods.

On the other hand, some studies did not meet the strict conditions to be considered in this review, but due to their importance regarding the similarities of the electromagnetic radiation types involved and the effects found in many cases, they provide important supplementary evidence, as we will see in the next paragraphs.

For example, mobile phone users had an increased risk of headache (one of the typical symptoms for RF sickness near base station antennas) compared with non-users, and the risk of headache was also increased in those who had a longer daily call duration and higher daily call frequency (Wang et al., 2017). The same was also seen with cancer (Hardell et al., 2007). On the other hand, the symptoms caused by wireless smart meters were similar to those reported by people exposed to RF fields emitted by mobile phones (Lamech, 2014).

Table 1
Studies that met the selected criteria.

N°	Reference and country	Antenna type	Study design	Diseases and symptoms found/not found	Main conclusions
1 Y RS	Santini et al. (2002), 2003a and 2003b France	Base station antennas GSM 900 and 1800 MHz	Questionnaire survey in 530 people	Effects found on: -tiredness -headache -sleep disturbance -discomfort -irritability -depression -memory loss -dizziness -libido decrease -visual perturbations	Effects occur up to a distance of 300 m from the antenna. Older subjects are more sensitive. Also, hat the facing location is the worst position for some symptoms s tudied, especially for distances till 100 m from base stations. The frequency of reported complaints is significantly higher for women in comparison with men
2 Y RS	Gómez-Perretta et al., 2013 Spain	Base station antennas GSM 900 and 1800 MHz	Questionnaire survey in 101 people and electric field measurements	Effects found on: -fatigue -irritability -headache -nausea -appetite loss -discomfort -sleep disturbance -depression -difficulty in concentration -dizziness	Significant correlation between the declared severity of the symptoms and the measured power density. The separation of respondents into two different exposure groups also showed an increase of the declared severity in the group with the higher exposure. The incidence of most of the symptoms was related to exposure levels, independently of the demographic variables and some possible risk factors. Health changes related with GSM exposure seem to occur in a manner unrelated with those fears
3 Y RS	Bortkiewicz et al. (2004) Poland	Base station antennas	Review of previous publications	Effects found on: -circulatory system -sleep disturbances -irritability depression -blurred vision -concentration -difficulties nausea -lack of appetite -headache -vertigo	Relationship between the incidence of individual symptoms, the level of exposure, and the distance. This association was observed in both groups of persons, those who linked their complaints with the presence of the base station and those who did not notice such a relation.
4 Y C	Eger et al. (2004) Germany	2 Base station antennas	Number of cancer cases in the selected population (1045 resident) in Naila to compare results an inner area (within a distance of 400 m from the base station antennas) and outer area (beyond 400 m).	The number of newly developed cancer cases in the inner area is more than the expected number taken from the cáncer register, which represents the total population being irradiated. The group who had lived during the past five years within a distance of 400 m from the Base station antennas have a two times higher risk of developing cancer than that of the average population. The relative risk of getting cancer in the inner área compared with the Saarland cancer register is 1.7.	The risk of newly developing cancer was three times higher among those patients who had lived during past ten years (1994–2004), within a distance of 400 m From the cellular transmitter, in comparison to those who had lived further away.
5 Y C	Wolf and Wolf (2004) Israel	1 Base station antenna	A cancer incidence study to investigate the incidence of cancer cases of individuals (the cohort included 622 people) exposed to a Base station antenna, in comparison to those of a nearby clinic out of that area, to the national incidence rates of the whole country and to the incidence rates in the whole town of Netanya	There were 4.15 times more cases of cáncer in area A (breast carcinoma, ovary carcinoma, lung carcinoma, Hodgkin's disease, osteoid osteoma, and hypernephroma) than in the entire population.	The study indicates an association between an increased incidence of cancer and living in proximity to a Base station antenna.
6 Y RS	Hutter et al. (2006) Austria	10 Base station antennas in the 900 MHz band	Questionnaire survey in 365 subjects and exposure measurements	Effects found on: -headache -difficulties to concéntrate -Cold hands or feet No effects found on: -vertigo -palpitations -tremor -hot flushes -sweating -loss of apetite -loss of energy, -exhaustion -tiredness	Self-reported symptoms like headache and difficulties in concentrating show an association with microwave exposure from base stations, not attributable to subjects' fear of health effects from these sources. Other symptoms, like sleeping problems, seem to be more due to fear of adverse health effects than actual exposure.

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Table 1 (*continued*)

N°	Reference and country	Antenna type	Study design	Diseases and symptoms found/not found	Main conclusions
				-feeling strained -sleep	
7 Y RS	Abdel-Rassoul et al. (2007) Egypt	Base station antennas (GSM)	Questionnaire survey on 85 exposed persons and 80 controls	Effects found on: -headache -memory changes -dizziness -tremors -depressive symptoms -sleep disturbance No effects found on: -Blurred visión -Irritability -Lack of concentration	The prevalence of neuropsychiatric complaints were significantly higher among exposed inhabitants than controls. Inhabitants living nearby mobile phone base stations are at risk for developing neuropsychiatric problems and some changes in the performance of neurobehavioral functions either by facilitation or inhibition.
8 N CBP	Augner and Hacker (2009) Austria	Base station antennas	Questionnaire survey on fifty-seven participants and saliva samples	Self-declared base station neighbors (≤100 m) had significantly higher concentrations of alpha-amylase in their saliva, higher rates in symptoms, somatization, obsessive-compulsive, anxiety, phobic anxiety. There were no differences in EMF-related health concern scales.	Self-declared base station neighbors are more strained than others. EMF-related health concerns cannot explain these findings.
9 N RS	Blettner et al. (2009) Berg-Beckhoff et al. (2009) Germany	Base station antennas (GMS 900 and 1800 and UMTS 2170)	Questionnaire survey on 30,047 participants and geo-coding information on the residence distance (less or more than 500 m) to the nearest mobile phone base station. In a second phase RF measurements were conducted for a sub-sample in the households of 1500 persons	The mailed questionnaire included a list of 38 symptoms that have been reported in previous studies to be possibly associated with RF-EMF exposure	Participants who were concerned about or attributed adverse health effects to mobile phone base stations and those living in the vicinity of a mobile phone base station (500 m), reported slightly more health complaints tan others. The observed slightly higher prevalence of health complaints near base stations cannot be explained by attributions or concerns alone. The worries and health complaints of people living close to mobile phone base stations need to be taken seriously. Measured RF-EMFs emitted from mobile phone base stations were not associated with health disturbances. However, the study shows that sleep disturbances and health complaints are related to the attribution of adverse health effects to mobile phone base stations.
10 Y RS C	Kundi and Hutter (2009) Austria	Base station antennas	Review of previous publications	Effects found on: Adverse neurobehavioral symptoms or cancer	There are indications from epidemiology that such exposures affect wellbeing and health weakly supported by human provocation studies and an inconclusive body of evidence from animal and in vitro studies. Cross-sectional investigations of subjective health as a function of distance or measured field strength, despite differences in methods and robustness of study design, found indications for an effect of exposure that is likely independent of concerns and attributions. Two ecological studies of cancer in the vicinity of base stations report both a strong increase of incidence within a radius of 350 and 400 m respectively. Due to the limitations inherent in this design no firm conclusions can be drawn, but the results underline the urgent need for a comprehensive investigation of this issue
11 Y C	Eger and Jahn (2010) Germany	Base station antennas	Questionnaire survey on 255 persons	Effects found on: -sleep problems -depression -headaches -cerebral affections -concentration difficulties -joint problems -infections -skin problems	A significant relationship between mean exposure levels of the study participants and reported health symptoms. Within the 400-m radius around the transmitter, a higher symptom rate could be documented for 14 out of 19 symptom groups in the highest exposure groups compared to groups

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Table 1 (*continued*)

N°	Reference and country	Antenna type	Study design	Diseases and symptoms found/not found	Main conclusions
				-dizziness -cardiovascular problems -disturbance of equilibrium -visual problems -nosebleed -gastrointestinal problems No effects found on: -toothaches -hormonal imbalances -weight gain -weight loss	further away from the transmitter and the difference is statistically significant. Decreasing symptom scores in relation to decreasing mean exposure levels caused by cell phone transmitter emissions
12 N C	Elliott et al. (2010) Great Britain	Base station antennas	Data on all registered cases of cancer in children aged 0–4 in Great Britain and data on mobile phone base stations to investigate the risk of early childhood cancer associated with the mother's exposure to radiofrequency from and proximity to mobile phone base stations during pregnancy.	Of the 1397 cases, there were 251 brain and central nervous system cancers and 527 cases of leukaemia and non-Hodgkin's lymphoma. The study found no association between mobile phone base stations and risk of cáncer.	In this systematic national investigation the authors found no association between risk of cancer in young children and estimated exposures to radiofrequency from mobile phone base stations during pregnancy. However there is a research paper limitation on page 5: "our models did not include information on other sources of radiofrequency exposure, such as from microcells or picocells" and the city centers (especially) are full of these kind of antennas.
13 Y RS C	Khurana et al. (2010) international	Base station antennas	Review of previous publications	Effects found on: Adverse neurobehavioral symptoms or cancer	The authors identified a total of 10 epidemiological studies that assessed for putative health effects of mobile pone base stations. Seven of these studies explored the association between base station proximity and neurobehavioral effects and three investigated cancer. The authors found that eight of the 10 studies reported increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at distances <500 m from base stations.
14 N RS	Röösli et al. (2010) Switzerland	Base station antennas (GMS 900 and 1800 and UMTS 2170)	Systematic review	There are no adverse effects	Not indication of an association between any health outcome and RF-EMF exposure from mobile phone base stations at levels typically found in our everyday environment. There is also no evidence that EHS individuals are more susceptible to base station radiation than the rest of the population. The evidence for the absence of long-term effects is limited.
15 N CBP C	Yildirim et al. (2010) Turkey	Base station antennas	Blood samples to analise the micronucleus (MN) frequency and chromosomal aberrations on blood in people living around mobile phone base stations and healthy controls.	There was not a significant difference of MN frequency and chromosomal aberrations between the two study groups.	Mobile phones and their base stations do not produce important carcinogenic changes.
16 Y RS	Alazawi, 2011 Iran	8 Base station antennas	Questionnaire survey on 375 subjects. Not measurements	Effects found on: -headaches -sleep disturbances -irritability -depressive -tendencies -feeling of discomfort, -difficulties in concentration -memory loss -lowering of libido	This study shows that inhabitants living nearby mobile phone base stations are at risk for developing non specific health symptoms, the facing position appears to be the worst one for distances from cellular phone base stations <100 m. It is advisable that cellular phone base stations should not be sited closer than 300 m to populations, as a precautionary measure, sitting of base stations should be such as to minimize exposure of neighbors.
17 Y C	Dode et al. (2011) Brazil	Base station antennas	This research was conducted in a broad environmental context, aiming to verify if there is a spatial correlation between the Base station antennas and the cases of death by neoplasia during the period between 1996 and 2006 in Belo Horizonte municipality (Brazil).	The mortality rates and the relative risk were higher for the residents inside a radius of 500 m from the Base station antennas, compared to the average mortality rate of the entire city, and a decreased dose– response gradient was observed for residents who lived farther away from these base stations.	The research showed the existence of a spatial correlation between cases of death by neoplasia and the locations of the Base station antennas, in the Belo Horizonte municipality from 1996 to 2006.

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Table 1 (*continued*)

N°	Reference and country	Antenna type	Study design	Diseases and symptoms found/not found	Main conclusions
18 Y C	Li et al. (2012) Taiwan	Base station antennas	Population-based case–control study in Taiwan considerering incident cases aged 15 years or less and admitted in 2003–2007 for all neoplasm (n = 3481 children). Exposure of each study subject to radio frequency (RF) was indicated by the averaged annual power density within 5 years prior to the neoplasm diagnosis. Controls were randomly selected.	Taiwanese children with higher-than median exposure of RF potentially emitted from Base station antennas were at significantly increased risk of all neoplasms combined. Although there were also positive associations between RF power density and risks of brain neoplasm and leukaemia in children, such associations did not reach statistical significance.	This study noted a significantly increased risk of all neoplasms in children with higher-than-median RF exposure to Base station antennas. The slightly elevated risk was seen for leukaemia and brain neoplasm, but was not statistically significant.
19 N C	Stewart et al. (2012) Great Britain	1 Base station antennas (GMS 1800)	Data on cancer incidence and mortality accessing the medical information of near residents	The study cannot conclude that the base station is responsible for the incidence of cancer in the local residents	Although the age range for local residents with cancer in the suspected cluster was younger than might be generally expected, there was no evidence that their cancer incidence is associated with the mobile phone base station. 10 cancers were registered after installation of the base station. However, the collection of cancers does not fulfil the criteria for a cancer cluster; the cases are a mixed variety of relatively common cancers. No single type of cancer was dominant, all but one were common types of cancer and none were seen in a group not usually affected by that cancer. Data from primary and secondary care also provide evidence that lifestyle and family history factors could have contributed to some individual cases.
20 N RS	Islam and Mohammed (2014) Bangladesh	Base station antennas	Questionnaire survey on 220 adults living near a Base station antenna for at least one year in two selected areas	Half of the respondents experienced problems in sleeping patterns, recent episodes of headache or dizziness and mood change, anxiety, or depression. 11 respondents experienced some generalized burning sensation and 4 reported episodes of shaking or fits. 48 respondents mentioned one or more other health effects, such as mood changes/problem, buzzing in the head, hopelessness, palpitation, tachycardia, heaviness of chest, anorexia, diarrhoea, and skin diseases.	From the results of the study cannot conclude that the health effects are direct results of the base station antennas. However, the complaints were similar to those of other studies, which shows the importance of conducting further research to determine the effects of electromagnetic radiarion from base station antennas on human health and should be considered as a public health concern.
21 Y RS	Pachuau and Pachuau (2014) India	Base station antennas (GSM 900)	Questionnaire survey conducted on 64 adults (31 female, 33 male) and electric field measurements. Health symptoms of RF exposure faced by the inhabitants within 50 m and outside 50 m from the tower were analysed and compared.	Effects found on: -Muscle pain -Fatigue -Sleep disorder -Nausea -Skin problema -Dizziness -Feeling of discomfort -Difficulty in concentration -Memory loss -Visual disruption	Inhabitants living within 50 m had more health complaints than those living outside 50 m. It was also found that females had more complaints than males
22 Y RS	Shinjyo and Shinjyo (2014) Japan	2 base station antennas (CDMA 800 MHz and 2 GHz)	Medical examinations and health questionnaires comparing the health of 107 residents during the base station's operation and after its removal. Measurement of the power density	Effects found on: -fatigue -eye problems -sleep disturbances -dizziness -headache -tinnitus -nasal bleeding No effects found on: -tachycardia -tumours -skin problems -rhinitis -angina pectoris -hearing loss	A total of 34 residents suffered from health problems after installation of the 800 MHz antennas. Three months after their removal this number decreased to 13. There were 41 residents who had health problems after installation of the 2 GHz antennas, and this number decreased to 15 after removal of the 2 GHz antennas. In total 49 residents suffered from health problems during operation of both the 800 MHz and the 2 GHz antennas. However, this number decreased to 25 after removal of both sets of antennas.The residents had no prior knowledge about possible adverse health effects of RF-EMFs. Health problems of the residents were associated with the operation of the

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Table 1 (*continued*)

N°	Reference and country	Antenna type	Study design	Diseases and symptoms found/not found	Main conclusions
					mobile phone base station and these problems improved after its removal.
23 Y CBP	Gandhi et al. (2015) India	Base station antennas	Questionnaire survey and blood simples from 91 individuals, with 70% (63) residing in a populated area with a mobile phone base station (the sample group) and 30% (28) in a sparsely-populated zone without any nearby base stations (the control group). Radiofrequency field measurements	Effects found on: Genetic damage parameters of DNA migration length, damage frequency (DF) and damage index	Genetic damage was significantly increased in the sample group compared to that in the controls. The 2.5–4.5-fold increase in DNA damage in peripheral blood lymphocytes of persons staying near a mobile phone base station is of acute concern given that all neoplasia initiate via unrepaired DNA damage. In the light of the above observations and the statistically significant genetic damage observed in those residing within 300 m of a mobile phone base station in this study, it implies that the effects of radiations from mobile phone base stations cannot be overlooked, as unrepaired DNA damage can lead to cancer, precocious ageing and age-related effects.
24 Y CBP	Meo et al. (2015) Saudi Arabia	2 Base station antennas (925 MHz) near two schools	RF-EMF measurements and blood sample collection	Effects found on: -chronic hyperglycemia -increased HbA1c -diabetes mellitus	Students who were exposed to high EMFR generated by MPBS had significantly higher HbA1c and prevalence of pre diabetes mellitus compared to the students who exposed to low EMFR. EMFR appears to be another risk factor contributing to high levels of HbA1c and risk of type 2 diabetes mellitus.
25 Y RS	Pachuau et al. (2015) India	Base station antennas (GSM 900)	Questionnaire survey from 50 exposed and 50 control individuals. Power density measurements	Effects found on: -fatigue -sleep disruption -headache -dizziness -muscle pain -cramp No effects found on: -nausea -discomfort -difficulty in concentration -memory los -skin problems -visual disruption -hearing problem	Inhabitants living near mobile tower are having more health complaints than those inhabitants living in the area where there is no mobile tower
26 Y CBP	Al-Quzwini et al. (2016) Iraq	Base station antennas	Questionnaire survey. Two hundred couples (one hundred subfertile couples as a study group, and one hundred fertile couples as a control group. Semen analysis	Twenty-nine percentage of subfertile couples had exposure to environmental hazards (communication's tower beside their house-within 50 m), and 71% non-hazard. The duration of the exposure to the environmental factor ranged from 2 to 7 years.	The exposure to environmental hazards shows significant difference between the subfertile and the fertile men; as higher percentage of exposure to mobile phone tower among subfertile group, 29% versus 12% for the fertile group,
27 N RS	Baliatsas et al. (2016) The Netherlands	Base station antennas (GSM and UMTS)	Health records from 1069 adult participants, All participants were living within 500 m from the nearest bases station. A propagation model combined with a questionnaire was used to assess indoor exposure to RF-EMF from MPBS at T1. Estimation of exposure at T0 was based on number of antennas at T0 relative to T1.	Compared to the baseline period, there was a higher prevalence of symptoms theoretically relevant to EMF at T1. A significant increase was observed in the prevalence of ear symptoms and a two-fold (but not significant) increase in the prevalence of skin symptoms. Overall, the total prevalence was slightly lower at T1. A consistent association between UMTS exposure and different clusters of GP-registered symptoms, for the self-declared mobile phone base stations-sensitive group.	This before-after study found no evidence that RF-EMF exposure from mobile phone base stations is associated with the development of non-specific symptoms in the general population, corroborating recent observational studies. Subgroup analyses among people with self-reported sensitivity to base stations showed a higher prevalence for most symptoms at T1 compared to baseline and there was some indication for a higher risk of non-specific symptoms for the mobile phone base stations-sensitive group, in relation to exposure.
28 N RS	Klaps et al. (2016) Austria	Base station antennas	Meta-analysis based on the results of 17 studies	The effects of mobile phone base stations seem to be rather unlikely. However, nocebo effects occur.	It is unclear whether electromagnetic fields emitted by mobile phone base stations affect well-being in adults. The existing studies on this topic are highly inconsistent.
29 Y	Singh et al. (2016) India	4 Base station antennas		Effects found: -sleep disturbances	A majority of the subjects who were residing near the mobile base station

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Table 1 (*continued*)

N°	Reference and country	Antenna type	Study design	Diseases and symptoms found/not found	Main conclusions
RS CBP			Questionnaire survey and salivary analysis in 20 individuals (case group) and 20 (control group)	-headache -dizziness -irritability -concentration difficulties -hypertension	had various complaints. A majority of the study subjects had significantly lesser stimulated salivary secretion as compared to the control subjects. The effects of prolonged exposure to EMRs from mobile phone base stations on the health and well-being of the general population cannot be ruled out.
30 Y RS	Premlal and Eldhose, 2017 India	14 Base station antennas	Questionnaire survey (229 persons) and power density measurements	Joint pain, sleep disorders, migraine related headaches and digestive problems	For 32 different diseases, only 4 were found to have obvious relation to the cell tower radiation. Females are more prone to the bad effects of cell tower radiation. The current Indian standard for cell tower exposure is inadequate for the safe living.
31 Y CBP	Taheri et al. (2017) Iran	Base station antennas	45 healthy individuals with their home near BTS antenna (exposed group) and 45 healthy subjects who were away from the antenna	In the exposed group, the whole number of white blood cells, the level of hematocrit, percent of monocytes, eosinophils and basophils were significantly lower than the control group. The number of red blood cells, their average volume and the mean concentration of hemoglobin were notably higher than the controls. There was not observed a significant difference between the two groups in hemoglobin, its mean concentration, platelet count, percent of lymphocytes and neutrophils as well as serum levels of cytokines IL-4, IL-10 and interferon γ.	The radiation of base station antennas influenced the blood and immune systems.
32 Y RS C	Vijay and Choudhary (2017) India	40 Base station antennas (900–1800 MHz)	Questionnaire survey	Effects found: - headache - depression - sleep disturbance - nausea - fatigue - asthma - cancer - Alzheimer's disease - multiple sclerosis - brain tumor.	The questionnaires show that people have some kind of physical or mental illness after the installation of mobile towers.
33 Y CBP	Zothansiama et al. (2017) India	6 Base station antennas (900–1800 MHz)	Questionnaire survey. Blood sample collection and lymphocyte culture. Power density measurement. Exposed group (n = 40) Control group (n = 40) The study was envisaged to evaluate the effect of RFR on the DNA damage and antioxidant status in cultured human peripheral blood lymphocytes of individuals residing in the vicinity of mobile phone base stations and comparing it with healthy controls.	Effects found: -higher frequency of micronuclei -decreased antioxidants	The analyses of data from the exposed group residing within a perimeter of 80 m of mobile base stations, showed significantly higher frequency of micronuclei when compared to the control group, residing 300 m away from themobile base station. The analysis of various antioxidants in the plasma of exposed individuals revealed a significant attrition in glutathione concentration, activities of catalase and superoxide dismutase and rise in lipid peroxidation when compared to controls. Multiple linear regression analyses revealed a significant association among decreased antioxidants and elevated miconuclei frequency with increasing RF power density. The persistence of DNA unrepaired damage leads to genomic instability which may lead to several health disorders including the induction of cancer.
34 Y RS	Meo et al. (2019) Saudi Arabia	Two different schools both situated nearby base station antennas (925 MHz)	Cognitive function, motor screening task and spatial working memory were tested, and also RF measurements were made.	There was a statistically significant impairment in the motor screening task and spatial working memory among students who were exposed to high RF generated by base station antennas (School 2: 10.021 μW/cm^2) compared to students who were exposed to lower levels of RF (School 1: 2.010 μW/cm^2).	High exposure to RF-EMF produced by base station antennas is associated with a decrease in fine and gross motor skills and spatial working memory and attention in school adolescents compared to students who had been exposed to low RF-EMF.

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Table 1 (*continued*)

N°	Reference and country	Antenna type	Study design	Diseases and symptoms found/not found	Main conclusions
35 Y RS	Ali et al. (2021) Iraq	Base station antennas (900–1800 MHz)	Questionnaire survey comparing two groups. The first group (n = 79) was located in a town with three cell phone towers with less than a hundred meters apart. The second study group (n = 79) was limited to the area almost empty from cell phone towers. Electric field measurements were made.	There was a significant association between health problems (skin problem, hair loss issues, sleeping difficulties, and fertility issues) and distance to towers (less distance, more problems: P-value < 0.05). In regards to health problems (abnormalities, blood pressure issues, tumours cases, and memory and concentration difficulties), the obtained results were not statistically significant.	The results showed an increase in both short- and long-term health problems near base stations antennas in general.
36 Y RS C	López et al., 2021 Spain	9 Base station antennas	Questionnaire survey on 268 persons, 174 in exposed área and 94 in control área, and EMF measurements	Effects found on -headache -dizziness -instability -tachycardias -nightmares No effects found on: -fainting	People who are exposed to higher radiation values present more severe headaches, dizziness and nightmares. 5.6% cancer cases in the study population, a percentage 10 times higher tan that of the total Spanish population.
37 N RS	Martin et al. (2021) France	Base station antennas	Questionnaire survey in 354 residents from buildings located at a distance of 250 m or less from the base station antennas in the main transmit beam of the antennas and home exposure measurements	No significant association between RF-EMF exposure and the overall symptoms score, nor between RF-EMF exposure from MPBSs and insomnia-like symptoms. There was a significant association between RF-EMF exposure and insomnia-like symptoms only for participants who attributed their symptoms to radiofrequencies.	The findings of the study do not support the hypothesis of an association between RF-EMF exposure and health outcomes, such as self-reported non-specific or insomnia-like symptoms in the general population. However, they may suggest a possible association between such exposure and insomnia-like symptoms among people reporting environmental concerns.
38 Y C	Rodrigues et al. (2021) Brazil	Base station antennas	This is an ecological study using capitals as the unit of analysis. The authors collected information on the number of deaths by cancer, gender, age group, gross domestic product per capita, death year, and the amount of exposure over a lifetime and investigated all cancer types and some specific types (breast, cervix, lung, and esophagus cancers).	For all cancers and for the specific types investigated (breast, cervix, lung, and esophagus cancers), the higher the exposure to RBS radiofrequency, the higher the median of mortality rate.	The results indicates that the exposure to radiofrequency electromagnetic fields from an RBS increases the rate of mortality by all cancers and specifically by breast, cervix, lung, and esophageal cancers. These conclusions are based on the fact that the findings of the study indicate that, the higher the RBS radiofrequency exposure, the higher the cancer mortality rate, especially for cervix cancer. The spatial analysis showed that the highest radiofrequency exposure was observed in a city located in the southern region of Brazil, which also showed the highest mortality rate for all types of cancer and specifically for lung and breast cancers.

4.1. Investigations with radar and radio/television antennas

In studies carried out in the last century, occupational exposure of people to microwave radiation (RF) related to military, industrial and radio uses, as well as radio waves, showed several types of effects: an increase in spontaneous abortions, changes in red and white blood cell counts and an increase in childhood, testicular and other cancers. These findings suggest that RF exposures are potentially carcinogenic and have other health effects; the author recommends precautionary measures to avoid unnecessary exposure (Goldsmith, 1997). An analysis of particular locations of diagnosed neoplasms indicates significantly higher morbidity rates in the military exposed to RF for alimentary tract cancers, skin tumours, neoplasms and cerebral and haematological/lymphatic malignancies. For haematological/lymphatic malignancies, the difference in morbidity between exposed and unexposed military was the largest. This may suggest that spontaneous neoplasms develop faster in the exposed group, with a shorter latency period than in those not exposed. In fact, in exposed subjects, the disease occurs 5–10 years earlier (Szmigielski et al., 2001). On the other hand, children exposed to radar electromagnetic radiation had less developed memory and attention, their reaction time was slower and their neuromuscular apparatus endurance was decreased (Kolodynski and Kolodynska, 1996).

In several studies performed around radio and television antennas, there was a significant decrease in the risk of cancer and leukaemia with increasing distance to the antennas (Maskarinec et al., 1994; Dolk et al., 1997a, 1997b; Hocking and Gordon, 2000; Michelozzi et al., 2002; Park et al., 2004). People exposed to a radio antenna shortwave broadcasting station in Schwarzenburg (Switzerland) had sleep disturbances, which were more frequent in exposed than in unexposed subjects (Altpeter et al., 2000).

Thus, the coincidences of similar effects from studies with different sources of electromagnetic radiation (but with similar pulsed, polarized and modulated radiation), such as radar or radio/television antennas, reinforce the conclusions of this review. Non-ionizing EMF are among the fastest growing forms of environmental pollution, its increase around the world in recent years has been exponential (Bandara and Carpenter, 2018) and symptoms reported today may be classic microwave/RF sickness (Levitt and Lai, 2010).

4.2. RF exposure incidents among diplomats (Havanna syndrome)

From late 2016 through August 2017, US government personnel on a diplomatic mission in Havana, Cuba, reported neurological symptoms, including cognitive, balance, visual and hearing disturbances, sleep

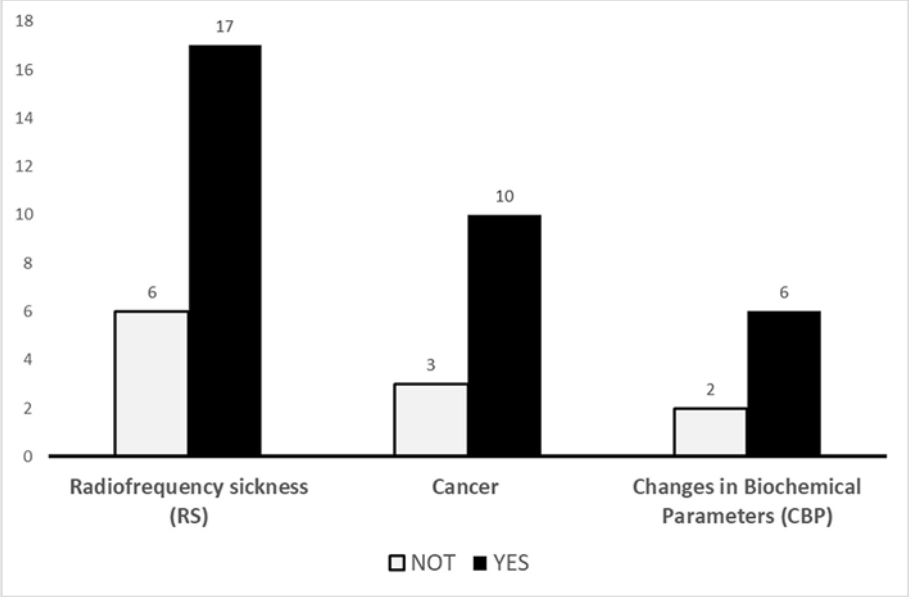

Fig. 1. Results on effects according to the study type considered.

disturbances and headaches. These individuals appeared to have sustained injuries to generalized brain networks with no associated history of head trauma (Swanson et al., 2018). They complained of cognitive decline, fatigue and headache, especially after cognitive exertion, and in some cases tinnitus, nausea and balance problems (Dyer, 2018). This mysterious disease that affected US and Canadian diplomats in Cuba (and later also in China) has confused the FBI, the State Department and US intelligence agencies.

The reported facts seem consistent with pulsed RF/microwave as the source of injuries to the affected diplomats (Golomb, 2018). The same conclusion was later reached by the National Academy of National Academies of Sciences (2020), who reported that many of the chronic or non-specific symptoms were consistent with known effects of RF, such as dizziness, headache, fatigue, nausea, anxiety, cognitive deficits and memory loss. In general, directed pulsed RF energy appears to be the most plausible mechanism to explain these cases. Such symptoms had already been described much earlier at the Moscow embassy (Lilienfeld et al., 1978; Johnson Lyakouris, 1998).

There are objective pathophysiological changes and health effects induced by EMF exposure that can biologically damage the organism and are noxious agents in healthy people (Belpomme and Irigaray, 2022).

4.3. Important laboratory studies

The United States National Toxicology Program (NTP) tested the two main modulation types used for mobile phones worldwide for GSM (2G) and UMTS (3G/4G), in a two-year rodent cancer bioassay under near-field exposure conditions; the experiments included additional assays for genotoxicity endpoints (Smith-Roe et al., 2020). They found clear evidence of carcinogenic activity, and more specifically malignant schwannomas of the heart, malignant gliomas of the brain and benign, malignant or complex pheochromocytomas (combined) of the adrenal medulla. They also found increased DNA damage (measured by the comet assay) in the frontal cortex of male mice, in the leukocytes of female mice and in the hippocampus of male rats, indicating that mobile phone EMF could cause DNA damage and consequent carcinogenesis. In a similar large carcinogenicity study by the Ramazzini Institute, Falcioni et al. (2018) examined far-field exposure to GSM 1800 MHz EMF and reported very similar results to the NTP study. Specifically, they also found increased incidence of tumours of the brain and heart in the mobile phone EMF-exposed Sprague-Dawley rats. Furthermore, these tumours are of the same histotype as those observed in some epidemiological studies on mobile phone users (Hardell et al., 2007).

Kostoff et al. (2020) emphasizes that most of the laboratory experiments conducted to date were not designed to identify the more severe adverse effects reflective of the real-life operating environment in which wireless radiation systems operate, as many experiments do not include pulsing and modulation of the carrier signal and the majority do not account for synergistic adverse effects of other toxic stimuli.

4.4. Importance of studies with biological parameters and those performed on animals and plants

Despite the scientific evidence shown in the studies carried out in many countries by different teams of researchers that we have reviewed, several studies conclude that no effects are found and blame it on risk perception and the nocebo effect (Wiedemann et al., 2006; Kowall et al., 2012; Freudenstein et al., 2015; Dieudonné, 2016; Klaps et al., 2016; Koh et al., 2020). However, the nocebo effect is not supported by objective data (Belpomme and Irigaray, 2022), by the results of cancer studies (Eger et al., 2004; Wolf and Wolf, 2004; Dode et al., 2011; Li et al., 2012; Rodrigues et al., 2021), by studies on changes in haematological parameters (Gandhi et al., 2015; Meo et al., 2015; Taheri et al., 2017; Zothansiama et al., 2017), by hormonal changes after long-term exposure (Eskander et al., 2012), by salivary secretion (Singh et al., 2016) and by effects on fertility (Al-Quzwini et al., 2016). Many reviews on the health effects of mobile phones have reached the same conclusions regarding their effects on male infertility (El-Hamd and Aboeldahab, 2018). Unfortunately, the studies that allude to the nocebo effect seem to be the ones taken into account by the World Health Organization (World Health Organization, 2015).

On the other hand, studies performed on animals or trees near base station antennas are especially important, because animals and plants cannot be aware of their proximity and therefore nocebo or psychosomatic effects cannot be attributed (Balmori, 2005, 2010; Balmori and Hallberg, 2007; Hässig et al., 2012; Lázaro et al., 2016; Waldmann-Selsam et al., 2016; Levitt et al., 2021). In fact, a similar result of this study for humans was found in a review on the significant ecological effects of RF EMF in 65% of the studies on vertebrates, birds and plants (Cucurachi et al., 2013).

Moreover, for these effects, perfectly plausible mechanisms of action

have already been proposed. Plasma membrane calcium channels and other voltage-gated ion channels are irregularly activated/inactivated by man-made EMF in both animals and plants, increasing intracellular [Ca^{2+}] and altering intracellular ion concentrations (Panagopoulos et al., 2002, 2021; Pall, 2016).

Under the influence of non-thermal intensities of microwave radiation, often there are important signals of some hazardous changes in cell metabolism. A significant increase of reactive oxygen species and nitrogen oxide generation in cells under non-thermal intensities has been detected both in vivo and in vitro (Yakymenko et al., 2011; Belpomme and Irigaray, 2022). Thus, the different findings clearly argue for a causal role of EMF in inducing free radical species, including overproduction of reactive oxygen and nitrogen species or suppression of antioxidant defence in cells (Belpomme and Irigaray, 2022). Furthermore, this exposure can result in DNA damage through oxidative stress with reactive oxygen species/free radical overproduction (Yakymenko et al., 2011; Kıvrak et al., 2017; Panagopoulos et al., 2021).

5. The Precautionary Principle

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is a private organization that issues exposure guidelines that are then adopted by governments, but it has been accused of having conflicts of interest (Hardell and Carlberg, 2020; Hardell et al., 2021). The ICNIRP (2010, 2020) limits are thousands of times above the levels where effects are recorded for both extremely low frequency and RF man-made EMF and account only for thermal effects, whereas the vast majority of recorded effects are non-thermal. These existing guidelines for public health protection only consider the effects of acute intense (thermal) exposures and do not protect from lower level long-term exposures (Israel et al., 2011; Yakymenko et al., 2011; Blank et al., 2015; Starkey, 2016; Belpomme and Irigaray, 2022). The exposure duration is crucial to assess the induced effects.

The Precautionary Principle is one of the fundamental principles of the European Union, governing policies related to the environment, health and food safety (Harremoes et al., 2013). This principle enables decision-makers to adopt precautionary measures when the scientific evidence regarding an environmental or human health factor is not certain regarding its safety. Therefore, despite the existing ample and rapidly increasing scientific evidence, no significant progress has been made over all these years, at least at the level of guidelines issued by the responsible authorities and official regulatory bodies. Some authors have pointed out that the source of funding correlates with study findings, and many systematic reviews and meta-analyses in this field have failed to correct for this source of funding bias, which has likely underestimated the evidence for causation (Carpenter, 2019). A growing number of scientists have been calling internationally on governments to raise their safety standards for RF-EMF (Blank et al., 2015; Hardell and Nyberg, 2020; Frank, 2021). Thus, there is an urgent need to adopt the Precautionary Principle and impose more restrictive levels (Zinelis, 2010; Yakymenko et al., 2011; Blank et al., 2015; Starkey, 2016).

6. Conclusion

In the current circumstances, it seems that the scientific experts in the field are very clear about the serious problems we are facing and have expressed this through important appeals (Blank et al., 2015; Hardell and Nyberg, 2020). However, the media, the responsible organizations (World Health Organization, 2015) and the governments are not transmitting this crucial information to the population, who remain uninformed. For these reasons, the current situation will probably end in a crisis not only for health but also for this technology itself, as it is unsustainable and harmful to the environment and the people.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abelin, T., Altpeter, E., Röösli, M., 2005. Sleep disturbances in the vicinity of the short-wave broadcast transmitter Schwarzenburg. Somnologie-Schlafforschung und Schlafmedizin 9 (4), 203–209.
Akkam, Y., A Al-Taani, A., Ayasreh, S., Almutairi, A., Akkam, N., 2020. Correlation of blood oxidative stress parameters to indoor radiofrequency radiation: a cross sectional study in Jordan. Int. J. Environ. Res. Publ. Health 17 (13), 4673.
Alazawi, S.A., 2011. Mobile phone base stations health effects. Diyala J. Med. 1 (1), 44–52.
Alhekail, Z.O., Hadi, M.A., Alkanhal, M.A., 2012. Public safety assessment of electromagnetic radiation exposure from mobile base stations. J. Radiol. Prot. 32 (3), 325.
Altpeter, E., Battaglia, M., Bader, A., Pfluger, D., Minder, C.E., Abelin, T., 2000, June. Ten years experience with epidemiological research in the vicinity of the short-wave broadcasting area Schwarzenburg: what does the story tell us. In: Proceedings of the International Conference on Cell Tower Siting. Salzburg, Austria, pp. 7–8.
Altpeter, E.S., Röösli, M., Battaglia, M., Pfluger, D., Minder, C.E., Abelin, T., 2006. Effect of short-wave (6–22 MHz) magnetic fields on sleep quality and melatonin cycle in humans: the Schwarzenburg shut-down study. Bioelectromagnetics 27 (2), 142–150.
Abdel-Rassoul, G., Abou El-Fateh, O., Abou Salem, M., Michael, A., Farahat, F., El-Batanouny, M., Salem, E., 2007. Neurobehavioral effects among inhabitants around mobile phone base stations. Neurotoxicology 28 (2), 434–440.
Admawi, H.K., 2021. Assessment of electromagnetic pollution in some hospitals and schools in Al-najaf city. J. Eng. 27 (3), 1–14.
Ali, M.T., Muhsen, Y.R., Chisab, R.F., Abed, S.N., 2021. Evaluation study of radio frequency radiation effects from cell phone towers on human health. Radioelectron. Commun. Syst. 64 (3), 155–164.
Al-Quzwini, O.F., Al-Taee, H.A., Al-Shaikh, S.F., 2016. Male fertility and its association with occupational and mobile phone towers hazards: an analytic study. Middle East Fertil. Soc. J. 21 (4), 236–240.
Altpeter, E., Battaglia, M., Bader, A., Pfluger, D., Minder, C.E., Abelin, T., 2000. Ten years experience with epidemiological research in the vicinity of the short-wave broadcasting area Schwarzenburg: what does the story tell us. In: Proceedings of the International Conference on Cell Tower Siting, vol. 78. Salzburg, Austria, pp. 127–132.
Aniołczyk, H., 1999. Electromagnetic field pattern in the environment of GSM base stations. Int. J. Occup. Med. Environ. Health 12 (1), 47–58.
Atzmon, I., Linn, S., Richter, E., Portnov, B.A., 2012. Cancer risks in the druze isifya village: reasons and RF/MW antennas. Pathophysiology 19 (1), 21–28.
Augner, C., Hacker, G.W., 2009. Are people living next to mobile phone base stations more strained? Relationship of health concerns, self-estimated distance to base station, and psychological parameters. Indian J. Occup. Environ. Med. 13 (3), 141.
Augner, C., Florian, M., Pauser, G., Oberfeld, G., Hacker, G.W., 2009. GSM base stations: short-term effects on well-being. Bioelectromagnetics 30 (1), 73–80.
Augner, C., Hacker, G.W., Oberfeld, G., Florian, M., Hitzl, W., Hutter, J., Pauser, G., 2010. Effects of exposure to GSM mobile phone base station signals on salivary cortisol, alpha-amylase, and immunoglobulin A. Biomed. Environ. Sci. 23 (3), 199–207.
Azimzadeh, M., Jelodar, G., 2019. Alteration of testicular regulatory and functional molecules following long-time exposure to 900 MHz RFW emitted from BTS. Andrologia 51 (9), e13372.
Baliatsas, C., van Kamp, I., Kelfkens, G., Schipper, M., Bolte, J., Yzermans, J., Lebret, E., 2011. Non-specific physical symptoms in relation to actual and perceived proximity to mobile phone base stations and powerlines. BMC Publ. Health 11 (1), 1–12.
Baliatsas, C., van Kamp, I., Bolte, J., Kelfkens, G., van Dijk, C., Spreeuwenberg, P., et al., 2016. Clinically defined non-specific symptoms in the vicinity of mobile phone base stations: a retrospective before-after study. Sci. Total Environ. 565, 714–720.
Balmori, A., 2005. Possible effects of electromagnetic fields from phone masts on a population of white stork (Ciconia ciconia). Electromagn. Biol. Med. 24 (2), 109–119.
Balmori, A., Hallberg, Ö., 2007. The urban decline of the house sparrow (Passer domesticus): a possible link with electromagnetic radiation. Electromagn. Biol. Med. 26 (2), 141–151.
Balmori, A., 2010. Mobile phone mast effects on common frog (Rana temporaria) tadpoles: the city turned into a laboratory. Electromagn. Biol. Med. 29 (1–12), 31–35.
Bandara, P., Carpenter, D.O., 2018. Planetary electromagnetic pollution: it is time to assess its impact. Lancet Planet. Health 2 (12), e512–e514.
Beekhuizen, J., Vermeulen, R., Kromhout, H., Bürgi, A., Huss, A., 2013. Geospatial modelling of electromagnetic fields from mobile phone base stations. Sci. Total Environ. 445, 202–209.
Belpomme, D., Irigaray, P., 2022. Why Electrohypersensitivity and Related Symptoms Are Caused by Non-ionizing Man-Made Electromagnetic Fields: an Overview and Medical Assessment. Environmental Research, 113374.
Berg-Beckhoff, G., Blettner, M., Kowall, B., Breckenkamp, J., Schlehofer, B., Schmiedel, S., et al., 2009. Mobile phone base stations and adverse health effects:

phase 2 of a cross-sectional study with measured radio frequency electromagnetic fields. Occup. Environ. Med. 66 (2), 124–130.
Bithell, J.F., 2010. Childhood cancer and proximity to mobile phone masts. Bmj 340.
Blank, M., Havas, M., Kelley, E., Lai, H., Moskowitz, J., 2015. International Appeal: scientists call for protection from non-ionizing electromagnetic field exposure. Eur. J. Oncol. 20 (3/4), 180–182.
Blettner, M., Schlehofer, B., Breckenkamp, J., Kowall, B., Schmiedel, S., Reis, U., et al., 2009. Mobile phone base stations and adverse health effects: phase 1 of a population-based, cross-sectional study in Germany. Occup. Environ. Med. 66 (2), 118–123.
Boehmert, C., Freudenstein, F., Wiedemann, P., 2020. A systematic review of health risk communication about EMFs from wireless technologies. J. Risk Res. 23 (5), 571–597.
Bortkiewicz, A., Zmyślony, M., Szyjkowska, A., Gadzicka, E., 2004. Subjective symptoms reported by people living in the vicinity of cellular phone base stations: review. Med. Pr. 55 (4), 345–351.
Boscolo, P., Di Sciascio, M.B., D'ostilio, S., Del Signore, A., Reale, M., Conti, P., et al., 2001. Effects of electromagnetic fields produced by radiotelevision broadcasting stations on the immune system of women. Sci. Total Environ. 273 (1–3), 1–10.
Breckenkamp, J., Blettner, M., Schüz, J., Bornkessel, C., Schmiedel, S., Schlehofer, B., Berg-Beckhoff, G., 2012. Residential characteristics and radiofrequency electromagnetic field exposures from bedroom measurements in Germany. Radiat. Environ. Biophys. 51 (1), 85–92.
Bürgi, A., Theis, G., Siegenthaler, A., Röösli, M., 2008. Exposure modeling of high-frequency electromagnetic fields. J. Expo. Sci. Environ. Epidemiol. 18 (2), 183–191.
Bürgi, A., Scanferla, D., Lehmann, H., 2014. Time averaged transmitter power and exposure to electromagnetic fields from mobile phone base stations. Int. J. Environ. Res. Publ. Health 11 (8), 8025–8037.
Carpenter, D.O., 2019. Extremely low frequency electromagnetic fields and cancer: how source of funding affects results. Environ. Res. 178, 108688.
Chen, H.Y., Chuang, C.Y., 2009. Currents induced in human bodies during radiofrequency exposure near a cellular phone base station. Electromagnetics 29 (1), 13–23.
Coggon, D., 2006. Health risks from mobile phone base stations. Occup. Environ. Med. 63 (5), 298–299.
Cooper, D., Hemmings, K., Saunders, P., 2001. Re: "Cancer incidence near radio and televisión transmitters in Great Britain. I. Sutton Coldfield transmitter"; II. All high power transmitters. Am. J. Epidemiol. 153, 202–204.
Cucurachi, S., Tamis, W.L., Vijver, M.G., Peijnenburg, W.J., Bolte, J.F., de Snoo, G.R., 2013. A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF). Environ. Int. 51, 116–140.
Danker-Hopfe, H., Dorn, H., Bornkessel, C., Sauter, C., 2010. Do mobile phone base stations affect sleep of residents? Results from an experimental double-blind sham-controlled field study. Am. J. Hum. Biol. 22 (5), 613–618.
De Giudici, P., Genier, J.C., Martin, S., Doré, J.F., Ducimetiere, P., Evrard, A.S., et al., 2021. Radiofrequency exposure of people living near mobile-phone base stations in France. Environ. Res. 194, 110500.
Dieudonné, M., 2016. Does electromagnetic hypersensitivity originate from nocebo responses? Indications from a qualitative study. Bioelectromagnetics 37 (1), 14–24.
Dode, A.C., Leao, M.M., Tjo Fde, A., Gomes, A.C., Dode, D.C., Dode, M.C., 2011. moreira CW, condessa VA, albinatti C, and caiaffa WT. Mortality by neoplasia and cellular telephone base stations in the belo horizonte municipality, minas gerais state, Brazil. Sci. Total Environ. 409, 3649–3665.
Dode, A.C., Leão, M.M., 2012. Comments on" Foster KR, Trottier L, comments on" mortality by neoplasia and cellular telephone base stations in the Belo Horizonte municipality, Minas Gerais state,. Sci. Total Environ. 442, 553–556 (2012. The Science of the total environment.
Dohle, S., Keller, C., Siegrist, M., 2012. Mobile communication in the public mind: insights from free associations related to mobile phone base stations. Hum. Ecol. Risk Assess. 18 (3), 649–668.
Dolk, H., Shaddick, G., Walls, P., Grundy, C., Thakrar, B., Kleinschmidt, I., Elliott, P., 1997a. Cancer incidence near radio and television transmitters in Great Britain I. Sutton Coldfield transmitter. Am. J. Epidemiol. 145 (1), 1–9.
Dolk, H., Elliot, G., Shaddick, G., Walls, P., Thakrar, B., 1997b. Cancer incidence near radio and television transmitters in great britain, Part 2. All high tower transmitters. Am. J. Epidemiol. 145, 10–17.
Dyer, O., 2018. Microwave weapon caused syndrome in diplomats in Cuba, US medical team believes. BMJ Br. Med. J. (Clin. Res. Ed.) 362.
Eger, H., Hagen, K.U., Lucas, B., Vogel, P., Voit, H., 2004. Einfluss der räumlichen Nähe von Mobilfunksendeanlagen auf die Krebsinzidenz. Umwelt-Medizin-Gesellschaft 17 (4), 326–335.
Eger, H., Jahn, M., 2010. Specific health symptoms and cell phone radiation in Selbitz (Bavaria, Germany)—evidence of a dose-response relationship. umwelt-medizin-gesellschaft 23, 130–139.
El-Hamd, M.A., Aboeldahab, S., 2018. Cell phone and male infertility: an update. J. Integrat. Nephrol. Androl. 5 (1), 1.
Elliott, P., Toledano, M.B., Bennett, J., Beale, L., De Hoogh, K., Best, N., Briggs, D.J., 2010. Mobile phone base stations and early childhood cancers: case-control study. Bmj 340.
Eltiti, S., Wallace, D., Ridgewell, A., Zougkou, K., Russo, R., Sepulveda, F., et al., 2007. Does short-term exposure to mobile phone base station signals increase symptoms in individuals who report sensitivity to electromagnetic fields? A double-blind randomized provocation study. Environ. Health Perspect. 115 (11), 1603–1608.
Elwood, J.M., 2003. Epidemiological studies of radio frequency exposures and human cancer. Bioelectromagnetics 24 (S6), S63–S73.
Eskander, E.F., Estefan, S.F., Abd-Rabou, A.A., 2012. How does long term exposure to base stations and mobile phones affect human hormone profiles? Clin. Biochem. 45 (1–2), 157–161.
Falcioni, L., Bua, L., Tibaldi, E., Lauriola, M., De Angelis, L., Gnudi, F., Belpoggi, F., 2018. Report of final results regarding brain and heart tumors in Sprague-Dawley rats exposed from prenatal life until natural death to mobile phone radiofrequency field representative of a 1.8 GHz GSM base station environmental emission. Environ. Res. 165, 496–503.
Foster, K.R., Trottier, L., 2012. Comments on" Mortality by neoplasia and cellular telephone base stations in the Belo Horizonte municipality, Minas Gerais state, Brazil" by AC Dode et al, 2011. In: Science of the Total Environment, vol. 409, pp. 3649–3665. The Science of the total environment, 450, 366-368.
Frank, J.W., 2021. Electromagnetic fields, 5G and health: what about the precautionary principle? J. Epidemiol. Community Health 75 (6), 562–566.
Frei, P., Mohler, E., Braun-Fahrländer, C., Fröhlich, J., Neubauer, G., Röösli, M., 2012. Cohort study on the effects of everyday life radio frequency electromagnetic field exposure on non-specific symptoms and tinnitus. Environ. Int. 38 (1), 29–36.
Freudenstein, F., Wiedemann, P.M., Brown, T.W., 2015. Exposure perception as a key indicator of risk perception and acceptance of sources of radio frequency electromagnetic fields. J. Environ. Public Health 2015, 9. https://doi.org/10.1155/2015/198272.
Gandhi, G., Kaur, G., Nisar, U., 2015. A cross-sectional case control study on genetic damage in individuals residing in the vicinity of a mobile phone base station. Electromagn. Biol. Med. 34 (4), 344–354.
Goldsmith, J.R., 1997. Epidemiologic evidence relevant to radar (microwave) effects. Environ. Health Perspect. 105 (Suppl. 6), 1579–1587.
Golomb, B.A., 2018. Diplomats' mystery illness and pulsed radiofrequency/microwave radiation. Neural Comput. 30 (11), 2882–2985.
Gómez-Perretta, C., Navarro, E.A., Segura, J., Portolés, M., 2013. Subjective symptoms related to GSM radiation from mobile phone base stations: a cross-sectional study. BMJ Open 3 (12), e003836.
Ha, M., Lim, H.J., Cho, S.H., Choi, H.D., Cho, K.Y., 2003. Incidence of cancer in the vicinity of Korean AM radio transmitters. ArchivE Environ. Health 58 (12), 756–762.
Ha, M., Im, H., Lee, M., Kim, H.J., Kim, B.C., Gimm, Y.M., Pack, J.K., 2007. Radio-frequency radiation exposure from AM radio transmitters and childhood leukemia and brain cancer. Am. J. Epidemiol. 166 (3), 270–279.
Hansson, B., Thors, B., Törnevik, C., 2011. Analysis of the effect of mobile phone base station antenna loading on localized SAR and its consequences for measurements. Bioelectromagnetics 32 (8), 664–672.
Hallberg, Ö., Johansson, O., 2002. Melanoma incidence and frequency modulation (FM) broadcasting. ArchivE Environ. Health 57 (1), 32–40.
Hardell, L., Carlberg, M., Söderqvist, F., Mild, K.H., Morgan, L.L., 2007. Long-term use of cellular phones and brain tumours: increased risk associated with use for > or =10 years. Occup. Environ. Med. 64 (9), 626–632 submitted for publication.
Hardell, L., Carlberg, M., Hedendahl, L.K., 2018. Radiofrequency radiation from nearby base stations gives high levels in an apartment in Stockholm, Sweden: a case report. Oncol. Lett. 15 (5), 7871–7883.
Hardell, L., Carlberg, M., 2020. [Comment] Health risks from radiofrequency radiation, including 5G, should be assessed by experts with no conflicts of interest. Oncol. Lett. 20 (4), 1, 1.
Hardell, L., Nyberg, R., 2020. [Comment] Appeals that matter or not on a moratorium on the deployment of the fifth generation, 5G, for microwave radiation. Mole. Clinic. Oncol. 12 (3), 247–257.
Hardell, L., Nilsson, M., Koppel, T., Carlberg, M., 2021. Aspects on the international commission on non-ionizing radiation protection (ICNIRP) 2020 guidelines on radiofrequency radiation. J. Cancer Sci. Clinic. Therapeutics 5 (2), 250–285.
Harremoes, P., Gee, D., MacGarvin, M., Stirling, A., Keys, J., Wynne, B., Vaz, S.G. (Eds.), 2013. The Precautionary Principle in the 20th Century: Late Lessons from Early Warnings. Routledge, London.
Hässig, M., Jud, F., Spiess, B., 2012. Increased occurrence of nuclear cataract in the calf after erection of a mobile phone base station. Schweizer Archiv Fur Tierheilkunde 154 (2), 82–86.
Henderson, S.I., Bangay, M.J., 2006. Survey of RF exposure levels from mobile telephone base stations in Australia. Bioelectromagnetics: J. Bioelectromag. Soc., Soc. Phys. Regul. Biol. Med., European Bioelectromag. Assoc. 27 (1), 73–76.
Hinrichs, H., Heinze, H.J., Rotte, M., 2005. Human sleep under the influence of a GSM 1800 electromagnetic far field. Somnologie-Schlafforschung und Schlafmedizin 9 (4), 185–191.
Hocking, B., Gordon, I.R., Grain, H.L., Hatfield, G.E., 1996. Cancer incidence and mortality and proximity to TV towers. Med. J. Aust. 165 (11–12), 601–605.
Hocking, B., Gordon, I., 2000. Decreased survival for childhood leukemia in proximity to TV towers. In: Poster Presented at the Annual Scientific Meeting of the Royal Australian College of Physicians in Adelaide. SA, Australia.
Hutter, H.P., Moshammer, H., Wallner, P., Kundi, M., 2006. Subjective symptoms, sleeping problems, and cognitive performance in subjects living near mobile phone base stations. Occup. Environ. Med. 63 (5), 307–313.
ICNIRP, 2010. Guidelines for limiting exposure to time-varying electric and magnetic fields (1Hz to 100 kHz). Health Phys. 99 (6), 818–836.
ICNIRP, 2020. Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). Health Phys. 118 (5), 483–524.
Islam, S., Mohammed, S., 2014. Awareness and self-reported health hazards of electromagnetic waves from mobile phone towers in Dhaka, Bangladesh: a pilot study. Adv. Pub. Health 2014, 7. https://doi.org/10.1155/2014/952832, 952832.
Johnson Lyakouris, A.G., 1998. Radiofrequency (RF) sickness in the Lilienfeld study: an effect of modulated microwaves? ArchivE Environ. Health 53, 3, 1998.

Kazaure, J.S., Matthew, U.O., Okafor, N.U., Okey, O.D., 2021. Telecommunication network performances and evaluation of radio frequency electromagnetic radiation: health effects of the RF-EMR GSM base stations. Int. J. Inf. Commun. Technol. Hum. Dev. 13 (3), 16–37.
Keow, M.A., Radiman, S., 2006. Assessment of radiofrequency/microwave radiation emitted by the antennas of rooftop-mounted mobile phone base stations. Radiat. Protect. Dosim. 121 (2), 122–127.
Khurana, V.G., Hardell, L., Everaert, J., Bortkiewicz, A., Carlberg, M., Ahonen, M., 2010. Epidemiological evidence for a health risk from mobile phone base stations. Int. J. Occup. Environ. Health 16 (3), 263–267.
Kıvrak, E.G., Yurt, K.K., Kaplan, A.A., Alkan, I., Altun, G., 2017. Effects of electromagnetic fields exposure on the antioxidant defense system. J. Micros. Ultrastruct. 5 (4), 167–176.
Klaps, A., Ponocny, I., Winker, R., Kundi, M., Auersperg, F., Barth, A., 2016. Mobile phone base stations and well-being—a meta-analysis. Sci. Total Environ. 544, 24–30.
Koh, T.H., Choi, J.W., Seo, M., Choi, H.D., Kim, K., 2020. Factors affecting risk perception of electromagnetic waves from 5G network base stations. Bioelectromagnetics 41 (7), 491–499.
Kolodynski, A.A., Kolodynska, V.V., 1996. Motor and psychological functions of school children living in the area of the Skrunda Radio Location Station in Latvia. Sci. Total Environ. 180 (1), 87–93.
Kostoff, R.N., Heroux, P., Aschner, M., Tsatsakis, A., 2020. Adverse health effects of 5G mobile networking technology under real-life conditions. Toxicol. Lett. 323, 35–40.
Kundi, M., Hutter, H.P., 2009. Mobile phone base stations—effects on wellbeing and health. Pathophysiology 16 (2–3), 123–135.
Kowall, B., Breckenkamp, J., Blettner, M., Schlehofer, B., Schüz, J., Berg-Beckhoff, G., 2012. Determinants and stability over time of perception of health risks related to mobile phone base stations. Int. J. Publ. Health 57 (4), 735–743.
Lamech, F., 2014. Self-reporting of symptom development from exposure to radiofrequency fields of wireless smart meters in Victoria, Australia: a case series. Alternative Ther. Health Med. 20 (6), 28.
Lázaro, A., Chroni, A., Tscheulin, T., Devalez, J., Matsoukas, C., Petanidou, T., 2016. Electromagnetic radiation of mobile telecommunication antennas affects the abundance and composition of wild pollinators. J. Insect Conserv. 20 (2), 315–324.
Lemaire, T., Wiart, J., De Doncker, P., 2016. Variographic analysis of public exposure to electromagnetic radiation due to cellular base stations. Bioelectromagnetics 37 (8), 557–562.
Leitgeb, N., Schröttner, J., Cech, R., Kerbl, R., 2008. EMF-protection sleep study near mobile phone base stations. Somnologie-Schlafforschung und Schlafmedizin 12 (3), 234–243.
Levitt, B.B., Lai, H., 2010. Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays. Environ. Rev. 18 (NA), 369–395.
Levitt, B.B., Lai, H.C., Manville, A.M., 2021. Effects of Non-ionizing Electromagnetic Fields on Flora and Fauna, Part 2 Impacts: How Species Interact with Natural and Man-Made EMF. Reviews on Environmental Health.
Li, C.Y., Liu, C.C., Chang, Y.H., Chou, L.P., Ko, M.C., 2012. A population-based case–control study of radiofrequency exposure in relation to childhood neoplasm. Sci. Total Environ. 435, 472–478.
Lilienfeld, A.M., Tonascia, J., Tonascia, S., et al., 1978. Foreign Service Health Status Study. Department of State, Washington, DC. Final report contract no. 6025-619037 (NTS publication PB-288163).
López, I., Félix, N., Rivera, M., Alonso, A., Maestú, C., 2021. What is the radiation before 5G? A correlation study between measurements in situ and in real time and epidemiological indicators in Vallecas, Madrid. Environ. Res. 194, 110734.
Lyare, R.N., Volskiy, V., Vandenbosch, G.A., 2019. Study of the correlation between outdoor and indoor electromagnetic exposure near cellular base stations in Leuven, Belgium. Environ. Res. 168, 428–438.
Martens, A.L., Slottje, P., Smid, T., Kromhout, H., Vermeulen, R.C., Timmermans, D.R., 2018. Longitudinal associations between risk appraisal of base stations for mobile phones, radio or television and non-specific symptoms. J. Psychosom. Res. 112, 81–89.
Martens, A.L., Slottje, P., Timmermans, D.R., Kromhout, H., Reedijk, M., Vermeulen, R. C., Smid, T., 2017. Modeled and perceived exposure to radiofrequency electromagnetic fields from mobile-phone base stations and the development of symptoms over time in a general population cohort. Am. J. Epidemiol. 186 (2), 210–219.
Martin, S., De Giudici, P., Genier, J.C., Cassagne, E., Doré, J.F., Ducimetière, P., et al., 2021. Health disturbances and exposure to radiofrequency electromagnetic fields from mobile-phone base stations in French urban areas. Environ. Res. 193, 110583.
Maskarinec, G., Cooper, J., Swygert, L., 1994. Investigation of increased incidence in childhood leukemia near radio towers in Hawaii: preliminary observations. J. Environ. Pathol. Toxicol. Oncol. 13 (1), 33–37.
McKenzie, D.R., Yin, Y., Morrell, S., 1998. Childhood incidence of acute lymphoblastic leukemia and exposure to broadcast radiation in Sydney—a second look. Aust. N. Z. J. Publ. Health 22 (3 Suppl. l), 360–367.
Meo, S.A., Alsubaie, Y., Almubarak, Z., Almutawa, H., AlQasem, Y., Hasanato, R.M., 2015. Association of exposure to radio-frequency electromagnetic field radiation (RF-EMFR) generated by mobile phone base stations with glycated hemoglobin (HbA1c) and risk of type 2 diabetes mellitus. Int. J. Environ. Res. Publ. Health 12 (11), 14519–14528.
Meo, S.A., Almahmoud, M., Alsultan, Q., Alotaibi, N., Alnajashi, I., Hajjar, W.M., 2019. Mobile phone base station tower settings adjacent to school buildings: impact on students' cognitive health. Am. J. Men's Health 13 (1), 1557988318816914.
Michelozzi, P., Ancona, C., Fusco, D., Forastiere, F., Perucci, C.A., 1998. Risk of leukemia and residence near a radio transmitter in Italy. Epidemiology 9 (4), S111.
Michelozzi, P., Capon, A., Kirchmayer, U., Forastiere, F., Biggeri, A., Barca, A., Perucci, C.A., 2002. Adult and childhood leukemia near a high-power radio station in Rome, Italy. Am. J. Epidemiol. 155 (12), 1096–1103.
Milham Jr., S., 1988. Increased mortality in amateur radio operators due to lymphatic and hematopoietic malignancies. Am. J. Epidemiol. 127 (1), 50–54.
Mortazavi, S.M.J., 2014. Subjective symptoms related to GSM radiation from mobile phone base stations: a cross-sectional study. J. Biomed. Phys. Eng. 4 (1).
Mortazavi, S.M.J., 2017. RE:"Modeled and perceived exposure to radiofrequency electromagnetic fields from mobile-phone base stations and the development of symptoms over time in a general population cohort". Am. J. Epidemiol. 186 (10), 1217, 1217.
National Academies of Sciences, 2020. Engineering, and medicine. An assessment of illness in US government employees and their families at overseas embassies. https://doi.org/10.17226/25889.
Navarro, E.A., Segura, J., Portolés, M., Gómez-Perretta de Mateo, C., 2003. The microwave syndrome: a preliminary study in Spain. Electromagn. Biol. Med. 22 (2–3), 161–169.
Neitzke, H.P., Osterhoff, J., Peklo, K., Voigt, H., 2007. Determination of exposure due to mobile phone base stations in an epidemiological study. Radiat. Protect. Dosim. 124 (1), 35–39.
Pachuau, L., Pachuau, Z., 2014. Study of cell tower radiation and its health hazards on human body. IOSR J. Appl. Phys. (IOSR-JAP) 2278–4861.
Pachuau, L., Pachuau, Z., Zothansiama, 2015. Comparisons of non specific health symptoms faced by inhabitants exposed to high and low power density from mobile phone tower radiation. Int. J. Recent Innov. Trends Comput. Commun. 3 (2), 94–98.
Pall, M., 2016. Electromagnetic fields act similarly in plants as in animals: probable activation of calcium channels via their voltage sensor. Curr. Chem. Biol. 10 (1), 74–82.
Panagopoulos, D.J., Karabarbounis, A., Margaritis, L.H., 2002. Mechanism for action of electromagnetic fields on cells. Biochem. Biophys. Res. Commun. 298, 95–102.
Panagopoulos, D.J., Karabarbounis, A., Yakymenko, I., Chrousos, G.P., 2021. Human-made electromagnetic fields: ion forced-oscillation and voltage-gated ion channel dysfunction, oxidative stress and DNA damage. Int. J. Oncol. 59 (5), 1–16.
Park, S.K., Ha, M., Im, H.J., 2004. Ecological study on residences in the vicinity of AM radio broadcasting towers and cancer death: preliminary observations in Korea. Int. Arch. Occup. Environ. Health 77 (6), 387–394.
Premlal, P.D., Eldhose, N.V., 2017. Mobile tower radiation-an assessment of radiation level and its health implications in the residential areas of western ghats in idukki, Kerala. Int. J. Appl. Eng. Res. 12 (20), 9548–9554.
Regel, S.J., Negovetic, S., Röösli, M., Berdiñas, V., Schuderer, J., Huss, A., et al., 2006. UMTS base station-like exposure, well-being, and cognitive performance. Environ. Health Perspect. 114 (8), 1270–1275.
Regel, S.J., Tinguely, G., Schuderer, J., Adam, M., Kuster, N., Landolt, H.P., Achermann, P., 2007. Pulsed radio-frequency electromagnetic fields: dose-dependent effects on sleep, the sleep EEG and cognitive performance. J. Sleep Res. 16 (3), 253–258.
Riddervold, I.S., Pedersen, G.F., Andersen, N.T., Pedersen, A.D., Andersen, J.B., Zachariae, R., et al., 2008. Cognitive function and symptoms in adults and adolescents in relation to rf radiation from UMTS base stations. Bioelectromagnetics: J. Bioelectromag. Soc., Soc. Phys. Regul. Biol. Med., European Bioelectromag. Assoc. 29 (4), 257–267.
Rodrigues, N.C.P., Dode, A.C., Andrade, M.K.D.N., O'Dwyer, G., Monteiro, D.L.M., Reis, I.N.C., et al., 2021. The effect of continuous low-intensity exposure to electromagnetic fields from radio base stations to cancer mortality in Brazil. Int. J. Environ. Res. Publ. Health 18 (3), 1229.
Röösli, M., Huss, A., 2008. Mobile phone base station exposure and symptoms. Environ. Health Perspect. 116 (2), A62–A63.
Röösli, M., Frei, P., Mohler, E., Hug, K., 2010. Systematic review on the health effects of exposure to radiofrequency electromagnetic fields from mobile phone base stations. Bull. World Health Organ. 88, 887–896.
Santini, R., Santini, P., Danze, J.M., Le Ruz, P., Seigne, M., 2002. Enquête sur la santé de riverains de stations relais de téléphonie mobile: I/Incidences de la distance et du sexe. Pathol. Biol. 50 (6), 369–373.
Santini, R., Santini, P., Le Ruz, P., Danze, J.M., Seigne, M., 2003a. Survey study of people living in the vicinity of cellular phone base stations. Electromagn. Biol. Med. 22 (1), 41–49.
Santini, R., Santini, P., Danze, J.M., Le Ruz, P., Seigne, M., 2003b. Symptoms experienced by people in vicinity of base stations: II/Incidences of age, duration of exposure, location of subjects in relation to the antennas and other electromagnetic factors. Pathol. Biol. 51 (7), 412–415.
Satta, G., Mascia, N., Serra, T., Salis, A., Saba, L., Sanna, S., et al., 2018. Estimates of environmental exposure to radiofrequency electromagnetic fields and risk of lymphoma subtypes. Radiat. Res. 189 (5), 541–547.
Schmiedel, S., Brüggemeyer, H., Philipp, J., Wendler, J., Merzenich, H., Schüz, J., 2009. An evaluation of exposure metrics in an epidemiologic study on radio and television broadcast transmitters and the risk of childhood leukemia. Bioelectromagnetics 30 (2), 81–91.
Shinjyo, T., Shinjyo, A., 2014. Significant decrease of clinical symptoms after mobile phone base station removal–an intervention study. Umwelt medizin gesellschaft (Environ. Med. Company) 27, 294–301.
Schoeni, A., Roser, K., Bürgi, A., Röösli, M., 2016. Symptoms in Swiss adolescents in relation to exposure from fixed site transmitters: a prospective cohort study. Environ. Health 15 (1), 1–8.
Seitz, H., Stinner, D., Eikmann, T., Herr, C., Röösli, M., 2005. Electromagnetic hypersensitivity (EHS) and subjective health complaints associated with

electromagnetic fields of mobile phone communication—a literature review published between 2000 and 2004. Sci. Total Environ. 349 (1–3), 45–55.
Singh, M.M., Pati, A.K., 2016. Effects of radiation emanating from base transceiver station and mobile phone on sleep, circadian rhythm and cognition in humans–a review. Biol. Rhythm. Res. 47 (3), 353–388.
Singh, K., Nagaraj, A., Yousuf, A., Ganta, S., Pareek, S., Vishnani, P., 2016. Effect of electromagnetic radiations from mobile phone base stations on general health and salivary function. J. Int. Soc. Prev. Community Dent. 6 (1), 54.
Smith-Roe, S.L., Wyde, M.E., Stout, M.D., Winters, J.W., Hobbs, C.A., Shepard, K.G., Witt, K.L., 2020. Evaluation of the genotoxicity of cell phone radiofrequency radiation in male and female rats and mice following subchronic exposure. Environ. Mol. Mutagen. 61 (2), 276–290.
Starkey, S.J., 2016. Inaccurate official assessment of radiofrequency safety by the advisory group on non-ionising radiation. Rev. Environ. Health 31 (4), 493–503.
Stewart, A., Rao, J.N., Middleton, J.D., Pearmain, P., Evans, T., 2012. Mobile telecommunications and health: report of an investigation into an alleged cancer cluster in Sandwell, West Midlands. Perspect. Public Health 132 (6), 299–304.
Swanson, R.L., Hampton, S., Green-McKenzie, J., Diaz-Arrastia, R., Grady, M.S., Verma, R., et al., 2018. Neurological manifestations among US government personnel reporting directional audible and sensory phenomena in Havana, Cuba. JAMA 319 (11), 1125–1133.
Szmigielski, S., Sobiczewska, E., Kubacki, R., 2001. Carcinogenic potency of microwave radiation: overview of the problem and results of epidemiological studies on Polish military personnel. Eur. J. Oncol. 6, 193–200.
Taheri, M., Roshanaei, G., Ghaffari, J., Rahimnejad, S., Khosroshahi, B.N., Aliabadi, M., Eftekharian, M.M., 2017. The effect of Base Transceiver Station waves on some immunological and hematological factors in exposed persons. Hum. Antibodies 25 (1–2), 31–37.
Urbinello, D., Joseph, W., Huss, A., Verloock, L., Beekhuizen, J., Vermeulen, R., et al., 2014. Radio-frequency electromagnetic field (RF-EMF) exposure levels in different European outdoor urban environments in comparison with regulatory limits. Environ. Int. 68, 49–54.
Viel, J.F., Clerc, S., Barrera, C., Rymzhanova, R., Moissonnier, M., Hours, M., Cardis, E., 2009. Residential exposure to radiofrequency fields from mobile phone base stations, and broadcast transmitters: a population-based survey with personal meter. Occup. Environ. Med. 66 (8), 550–556.
Vijay, S., Choudhary, M.P., 2017. Study on health effects of mobile tower radiation on human beings. Int. Res. J. Eng. Technol 4 (11), 1548–1552.
Waldmann-Selsam, C., Balmori-de la Puente, A., Breunig, H., Balmori, A., 2016. Radiofrequency radiation injures trees around mobile phone base stations. Sci. Total Environ. 572, 554–569.
Wang, J., Su, H., Xie, W., Yu, S., 2017. Mobile phone use and the risk of headache: a systematic review and meta-analysis of cross-sectional studies. Sci. Rep. 7 (1), 1–7.
Wallace, D., Eltiti, S., Ridgewell, A., Garner, K., Russo, R., Sepulveda, F., et al., 2010. Do TETRA (Airwave) base station signals have a short-term impact on health and well-being? A randomized double-blind provocation study. Environ. Health Perspect. 118 (6), 735–741.
World Health Organization (WHO), 2015. International EMF Project – Progress Report. https://cdn.who.int/media/docs/default-source/radiation-international-emf-project-reports/emf-iac-2016-progress-report.pdf?sfvrsn=7b2836c0_2.
Wiedemann, P.M., Thalmann, A.T., Grutsch, M.A., Schütz, H., 2006. The impacts of precautionary measures and the disclosure of scientific uncertainty on EMF risk perception and trust. J. Risk Res. 9 (4), 361–372.
Wolf, R., Wolf, D., 2004. Increased incidence of cancer near a cell-phone transmitter station. Int. J. Cancer Prev. 1 (2), 123–128.
Yakymenko, I., Sidorik, E., Kyrylenko, S., Chekhun, V., 2011. Long-term exposure to microwave radiation provokes cancer growth: evidences from radars and mobile communication systems. Exp. Oncol. 33, 62–70.
Yetiş, C., Kayili, M.T., 2021. Determination of EMF pollution in the context of urban health: the case of safranbolu. Comput. Res. Prog. Appl. Sci. Eng.: Transact. Civil Environ. Eng. 7, 1–10, 2021 Article ID: 2418.
Yildirim, M.S., Yildirim, A., Zamani, A.G., Okudan, N., 2010. Effect of mobile phone station on micronucleus frequency and chromosomal aberrations in human blood cells. Genet. Counsel. 21 (2), 243.
Zinelis, S.A., 2010. The precautionary principle: radiofrequency exposures from mobile telephones and base stations. Environ. Health Perspect. 118 (1), A16. A16.
Zothansiama, Zosangzuali, M., Lalramdinpuii, M., Jagetia, G.C., 2017. Impact of radiofrequency radiation on DNA damage and antioxidants in peripheral blood lymphocytes of humans residing in the vicinity of mobile phone base stations. Electromagn. Biol. Med. 36 (3), 295–305.
Zwamborn, A.P.M., Vossen, S.H.J.A., van Leersum, B.J.A.M., Ouwens, M.A., Mäkel, W. N., 2003. Effects of Global Communication System Radio-Frequency Fields on Well Being and Cognitive Functions of Human Subjects with and without Subjective Complaints.

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Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective☆

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ABSTRACT

Exposure to low frequency and radiofrequency electromagnetic fields at low intensities poses a significant health hazard that has not been adequately addressed by national and international organizations such as the World Health Organization. There is strong evidence that excessive exposure to mobile phone-frequencies over long periods of time increases the risk of brain cancer both in humans and animals. The mechanism(s) responsible include induction of reactive oxygen species, gene expression alteration and DNA damage through both epigenetic and genetic processes. *In vivo* and *in vitro* studies demonstrate adverse effects on male and female reproduction, almost certainly due to generation of reactive oxygen species. There is increasing evidence the exposures can result in neurobehavioral decrements and that some individuals develop a syndrome of "electro-hypersensitivity" or "microwave illness", which is one of several syndromes commonly categorized as "idiopathic environmental intolerance". While the symptoms are non-specific, new biochemical indicators and imaging techniques allow diagnosis that excludes the symptoms as being only psychosomatic. Unfortunately standards set by most national and international bodies are not protective of human health. This is a particular concern in children, given the rapid expansion of use of wireless technologies, the greater susceptibility of the developing nervous system, the hyperconductivity of their brain tissue, the greater penetration of radiofrequency radiation relative to head size and their potential for a longer lifetime exposure.
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1. Introduction

Electromagnetic fields (EMFs) are packets of energy that have no mass. They vary in frequency and wavelength. At the high end of the electromagnetic spectrum there are cosmic and X-rays that have enough energy to cause ionization, and therefore are known as ionizing EMFs. Below in frequency and energy are ultraviolet, visible light and infrared EMFs. Excessive exposure to ultraviolet EMFs poses clear danger to human health, but life on earth would not be possible without visible light and infrared EMFs. Below these forms of EMF are those used for communications (radiofrequency or RF-EMFs, 30 kHz-300 GHz) and those generated by electricity (extremely low-frequency or ELF-EMFs, 3 Hz-3 kHz). These EMFs do not have sufficient energy to directly cause ionization, and are therefore known as non-ionizing radiation. RF-EMFs at sufficient intensity cause tissue heating, which is the basis of operation of the microwave oven. However the question to be addressed here is human health effects secondary to exposures to non-ionizing EMFs at low intensities that do not cause measureable heating.

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In spite of a large body of evidence for human health hazards from non-ionizing EMFs at intensities that do not cause measureable tissue heating, summarized in an encyclopedic fashion in the Bioinitiative Report (www.bioinitiative.org), the World Health Organization (WHO) and governmental agencies in many countries have not taken steps to warn of the health hazards resulting from exposures to EMFs at low, non-thermal intensities, nor have they set exposure standards that are adequately health protective. In 2001 the International Agency for Research on Cancer (IARC, 2002), part of the WHO, declared ELF-EMFs to be "possibly carcinogenic to humans", and in 2011 they made a similar declaration for RF-EMFs (Baan et al., 2011; IARC, 2013). The classification of RF-EMFs as a "possible" human carcinogen was based primarily on evidence that long-term users of mobile phones held to the head resulted in an elevated risk of developing brain cancer. One major reason that the rating was not at "probable" or "known" was the lack of clear evidence from animal studies for exposure leading to cancer. The US National Toxicology Program has released preliminary results of a study of long term exposure of rats to cell phone radiation which resulted in a statistically significant increase in brain gliomas, the same cancer found in people after long-term cell phone use, and schwannomas, a tumor similar to the acoustic neuroma also seen after intensive mobile phone use (Wyde et al., 2016). Similar results in rats have been reported in an independent study at the Ramazzini Institute with exposures similar to those from a mobile phone base station (Falcioni et al., 2018). This evidence, in conjunction with the human studies, demonstrates conclusively that excessive exposure to RF-EMF results in an increased risk of cancer. In light of this new evidence for cancer in rodents in response to prolonged exposure to mobile phone frequencies, the IARC rating should be raised at least to "probable" (Group 2A) if not "known" (Group 1).

Unfortunately the International EMF Project of the WHO, which is part of the Department of Public Health, Environment and Social Determinants of Health in Geneva, has consistently minimized health concerns from non-ionizing EMFs at intensities that do not cause tissue heating (WHO, 2014). In this regard WHO has failed to provide an accurate and human health-protective analysis of the dangers posed to health, especially to the health of children, resulting from exposure to non-thermal levels of electromagnetic fields. The Department of Public Health, Environment and Social Determinates of Disease takes its advice on the issues related to human health effects of non-ionizing EMFs from the International Commission on Non-ionizing Radiation Protection (ICNIRP). Almost all members of the core group preparing the new Environmental Health Criteria (EHC) document for the WHO are members of ICNIRP (Starkey, 2016; Hardell, 2017), a non-goverment organization (NGO) whose members are appointed by other members. In spite of recent efforts to control for conflicts of interest, ICNIRP has a long record of close associations with industry (Maisch, 2006). When queried as to why the WHO would take recommendations from such a group, WHO staff replied that ICNIRP is an official NGO which works closely with the WHO. Why this should exclude other scientific research groups and public health professionals is unclear, particularly since most members of ICNIRP are not active researchers in this field. We are particularly concerned that a new WHO EHC document on RF-EMFs is scheduled to be released soon, and that the members of the EHC Core Group and the individuals whose assistance has been acknowledged are known to be in denial of serious non-thermal effects of RF-EMFs in spite of overwhelming scientific evidence to the contrary (Starkey, 2016; Hardell, 2017).

Others have dismissed the strong evidence for harm from ELF- and RF-EMFs by arguing that we do not know the mechanism whereby such low energetic EMFs might cause cancer and other diseases. We have definitive evidence that use of a mobile phone results in changes in brain metabolism (Volkow et al., 2011). We know that low-intensity ELF- and RF-EMFs generate reactive oxygen species (ROS), alter calcium metabolism and change gene expression through epigenetic mechanims, any of which may result in development of cancer and/or other diseases or physiological changes (see www.bioinitiative.org for many references). We do not know the mechanisms behind many known human carcinogens, dioxins and arsenic being two examples. Given the strength of the evidence for harm to humans it is imperative to reduce human exposure to EMFs. This is the essence of the "precautionary principle".

There are a number of reasons for our concern. In the past the major exposure of the general population to RF-EMFs came from radio and television signals. Now there are almost as many mobile phones as there are people in the world, all of them being exposed to RF-EMFs. There are mobile phone towers everywhere, and in many developing countries there are no land-lines that allow communication without exposure to RF-EMFs. There is rapid movement in many developed countries to place small cell transmitting devices (5G) operating at higher frequencies (24–70 GHz) every approximately 300 m along sidewalks in residential neighborhoods. There are other significant sources of exposure, coming from WiFi, smart meters and soon from automobiles operating without a human driver. Therefore human exposure has increased dramatically in recent years, and continues to increase rapidly. While we already are seeing harm from these exposures, the degree of harm will only increase with time because of the latency that is known to occur between exposure and development of diseases such as cancer.

Standards for protection of human health from EMFs vary greatly around the world. Many countries set standards based on the false assumption that there are no adverse health effects of RF-EMFs other than those that are caused by tissue heating. This is the case in North America, Australia and some European countries. Many countries from the former Soviet Union have much more restrictive standards. However information from cellular and human studies show biological effects that constitute hazards to human health at exposure levels that are often exceeded during daily life.

This report follows a recent non-official meeting in Geneva with WHO representives, where the authors urged WHO to acknowlege low intensity effects of ELF-EMFs and non-thermal health effects of RF-EMFs. This report does not attempt to present a complete overview of the subject [see the Bioinitiative Report (www.bioinitiative.org) for that] but rather to provide a holistic picture of the processes explaining most or all of the adverse effects of EMF exposures. It summarizes the evidence for cancer resulting from exposure to EMFs, and identifies other diseases or pathological conditions such as Alzheimer's disease and hypofertility that have been shown to be associated with excesive exposure to low-intensity EMFs. We also focus on electrohypersensitivity (EHS) in both children and adults and cognitive and behavioural problems in children resulting from the increasing exposure. Finally we discuss what is known about the mechanisms whereby non-thermal EMF radiation can cause disease with special reference to EMF-related free radical production and epigenetic and genetic mechanisms.

2. Mobile phone use and the risk for glioma, meningioma and acoustic neuroma

The brain is the main target for exposure to RF-EMF radiation during use of handheld wireless phones, both mobile and cordless phones (Cardis et al., 2008; Gandhi et al., 2012). An increased risk for brain tumors has been of concern for a long time. The results of the Swedish National Inpatient Register have documented an

increasing incidence of brain tumors in recent years (Carlberg and Hardell, 2017). In May 2011 RF radiation in the frequency range 30 kHz–300 GHz was evaluated to be a Group 2B, i.e. a "possible" human carcinogen, by IARC (Baan et al., 2011; IARC, 2013). This was based on an increased risk for glioma and acoustic neuroma in human epidemiological studies. In the following an updated summary is given of case-control studies on brain and head tumors; glioma, meningioma and acoustic neuroma. The Danish cohort study on 'mobile phone users' (Johansen et al., 2001; Schüz et al., 2006) is not included due to serious methodological shortcomings in the study design, including misclassification of exposure (see Söderqvist et al., 2012a).

2.1. Glioma

Glioma is the most common malignant brain tumor and represents about 60% of all central nervous system (CNS) tumors. Most of these are astrocytic tumors that can be divided into low-grade (WHO grades I-II) and high-grade (WHO grades III-IV). The most common glioma type is glioblastoma multiforme (WHO grade IV) with peak incidence in the age group 45–75 years and median survival less than one year (Ohgaki and Kleihues, 2005). Three research groups have provided results in case-control studies on glioma (Interphone, 2010; Coureau et al., 2014; Hardell and Carlberg, 2015). Hardell and colleagues have published results from case-control studies on use of wireless phones and brain tumor risk since the end of the 1990s (Hardell et al., 1990; for more discussion see Carlberg and Hardell, 2017).

A random effects model was used for meta-analyses of published studies, based on test for heterogeneity in the overall group ("all mobile"). Note that only the Hardell group also assessed use of cordless phones. Thus their reference category included cases and controls with no use of wireless phones in contrast to the other studies investigating only mobile phone use. In Table 1 results for highest cumulative use in hours of mobile phones is given. All studies reported statistically significant increased risk for glioma and the meta-analysis yielded an odds ratio (OR) = 1.90 [95% confidence interval (CI) = 1.31–2.76]. For ipsilateral mobile phone use the risk increased further to OR = 2.54 (95% CI = 1.83–3.52) in the meta-analysis based on 247 exposed cases and 202 controls.

Carlberg and Hardell (2014) found shorter survival in patients with glioblastoma multiforme associated with use of wireless phones compared with patients with no use. Interestingly mutation of the p53 gene involved in disease progression has been reported in glioblastoma multiforme in patients with mobile phone use ≥3 h per day. The mutation was statistically significantly correlated with shorter overall survival time (Akhavan-Sigari et al., 2014). Further support for the increased risk of glioma associated with mobile phone use has been obtained in additional analyses of parts of the Interphone study (Cardis et al., 2011; Grell et al., 2016; Momoli et al., 2017).

2.2. Meningioma

Meningioma is an encapsulated, well-demarked and rarely malignant tumor. It is the most common benign tumor and accounts for about 30% of intracranial neoplasms. It develops from the pia and arachnoid membranes that cover the CNS. It is slowly growing and gives neurological symptoms by compression of adjacent structures. The most common symptoms are headaches and seizures. The incidence is about two times higher in women than in men. Meningioma develops mostly among middle aged and older persons (Cea-Soriano et al., 2012). Carlberg and Hardell (2015) included meningioma in their case-control studies. The results of the meta-analysis for cumulative exposure in the highest category are given in Table 2. In total there was an increased (but not statistically significant) risk for cumulative exposure but the increased risk was statistically significant for ipsilateral use of mobile phones (OR = 1.49, 95% CI = 1.08–2.06).

2.3. Acoustic neuroma

Acoustic neuroma, also called vestibular schwannoma, is a benign tumor located on the eighth cranial nerve from the inner ear to the brain. It is usually encapsulated and grows in relation to the auditory and vestibular portions of the nerve. It grows slowly and due to the narrow anatomical space may give compression of vital brain stem structures. First symptoms of acoustic neuroma are usually tinnitus and hearing problems. Results for use of mobile phones in Interphone (2011) and Hardell et al. (2013) are given in Table 3. Statistically significant increased risk was found for cumulative ipsilateral use ≥1640 h yielding OR = 2.71 (95% CI = 1.72–4.28).

The study by Moon et al. (2014) was not included in the meta-analysis because data on cumulative mobile phone use with numbers of cases and controls were not given. Support of an increased risk was seen in the case-case part of the study (Moon et al., 2014) and also in the report by Sato et al. (2011). Pettersson et al. (2014) made a case-control study on acoustic neuroma in Sweden not overlapping the Hardell et al. (2013) study. An increased risk for the highest category of cumulative use of both mobile phone (≥680 h OR = 1.46, 95% CI = 0.98–2.17) and cordless phone (≥900 h OR = 1.67, 95% CI = 1.13–2.49) was found.Pettersson et al. (2014) was not included in the meta-analysis due to the many scientific shortcomings in the study, e.g. laterality analysis was not made for cordless phone, the numbers in the laterality analysis for mobile phone are not consistent in text and tables and the 'unexposed' reference category included subjects using either mobile and cordless phone, which is clearly not correct (Hardell and Carlberg, 2014).

Table 1
Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for glioma in case-control studies in the highest category of cumulative hours of mobile phone use.

	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone 2010						
Cumulative use ≥1640 h	210/154	1.40	1.03–1.89	100/62	1.96	1.22–3.16
Coureau et al., 2014						
Cumulative use ≥896 h	24/22	2.89	1.41–5.93	9/7	2.11	0.73–6.08
Carlberg and Hardell, 2015						
Cumulative use ≥1640 h	211/301	2.13	1.61–2.82	138/133	3.11	2.18–4.44
Meta-analysis						
Longest cumulative use	445/477	1.90	1.31–2.76	247/202	2.54	1.83–3.52

Table 2
Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for meningioma in case-control studies in the highest category of cumulative hours of mobile phone use.

	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone 2010						
Cumulative use ≥1640 h	130/107	1.15	0.81–1.62	46/35	1.45	0.80–2.61
Coureau et al., 2014						
Cumulative use ≥896 h	13/9	2.57	1.02–6.44	6/4	2.29	0.58–8.97
Carlberg and Hardell 2015						
Cumulative use ≥1640 h	141/301	1.24	0.93–1.66	67/133	1.46	0.98–2.17
Meta-analysis						
Longest cumulative use	284/417	1.27	0.98–1.66	119/172	1.49	1.08–2.06

Table 3
Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for acoustic neuroma in case-control studies in the highest category of cumulative hours of mobile phone use.

	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone 2011						
Cumulative use ≥1640 h	77/107	1.32	0.88–1.97	47/46	2.33	1.23–4.40
Hardell et al., 2013						
Cumulative use ≥1640 h	27/301	2.40	1.39–4.16	19/133	3.18	1.65–6.12
Meta-analysis						
Cumulative use ≥1640 h	104/408	1.73	0.96–3.09	66/179	2.71	1.72–4.28

2.4. In summary

Based on case-control studies there was a consistent finding of increased risk for glioma and acoustic neuroma associated with use of mobile phones. Similar results were found for cordless phones in the Hardell group studies, although such use was not reported by the other study groups. The findings are less consistent for meningioma although somewhat increased risk was seen in the meta-analysis of ipsilateral mobile phone use. A longer follow-up time is necessary for this type of slow growing tumor.

The results on glioma and acoustic neuroma are supported by results from animal studies showing co-carcinogenic and tumor promoting effects from RF-EMF (Tillmann et al., 2010; Lerchl et al., 2015). Recent results from the National Toxicology Program (NTP) study showed genotoxicity of RF radiation in rats and mice exposed to RF-EMF (Smith-Roe et al., 2017). That result supports previous findings of DNA strand breaks in rat brain cells exposed to RF-EMF (Lai and Singh, 1997).

Of importance also is that the results in the NTP and Ramazzini studies both demonstrated an increased incidence of tumors of the same type, glioma and malignant schwannoma, as has been seen in humans with mobile phone use (Wyde et al., 2016; Falcioni et al., 2018). Acoustic neuroma (vestibular schwannoma) is a similar type of tumor as malignant schwannoma, although benign. In fact, rates of brain tumors are increasing in Sweden and use of wireless phones has been suggested to be the cause (Hardell and Carlberg. 2017).

3. Other diseases and pathological conditions attributed to exposure to low-intensity EMFs

The evidence for harm from RF-EMF is strongest for cancer as a consequence of intensive mobile phone use, especially gliomas, glioblastomas and acoustic neuromas. But there is other evidence for elevation in risk of leukemia among children living near to very high intensity radio transmission towers (Michelozzi et al., 2002; Ha et al., 2007). This is particularly interesting because leukemia is the cancer most associated with elevated exposure to ELF-EMFs arising from power lines (Ahlbom et al., 2000; Greenland et al., 2000). There is some evidence for elevations in breast cancer risk among women who wear their mobile phones in their bra (West et al., 2013). Heavy use of a mobile phone was associated with significantly elevated rates of ipsilateral parotid tumors in studies from both Israel (Sadetzki et al., 2007) and China (Duan et al., 2011). No increased risk was found in a Swedish study, but the results were limited by low number of participants and lack of data on heavy and long-term use of wireless phones (Söderqvist et al., 2012b).

There are other significant human health hazards of concern. There is strong animal and human evidence that exposure to RF-EMFs as well as ELF-EMFs reduces fertility in both males (reviewed by McGill and Agarwal, 2014) and females (Roshangar et al., 2014). An association between spontaneous abortion and non-thermal EMF exposure including ELF-EMFs was reported in several case-control studies (Dodge, 1970; Juutilainen et al., 1993; Li et al., 2017). The increased use of mobile phones and increased exposure coming from WiFi, smart meters and other wireless devices has been paralled in time with male hypofertility and sperm abnormalities in semen (Rolland et al., 2013). These effects may be related to holding an active wireless laptop in a man's lap or having an active mobile phone on their belt, but more study is needed. There is evidence that isolated human sperm exposed to RF-EMFs are damaged by generation of reactive oxygen species (Agarwal et al., 2009).

There are other diseases or physiologic alterations which have been reported to be associated with exposure to non-thermal EMFs in humans and in animals (Belyaev et al., 2016). Alzheimer disease has been shown to be significantly associated with chronic ELF-EMF occupational exposure in prospective epidemiological studies (García et al., 2008; Davanipour and Sobel, 2009). Exposure to RF-EMFs has been reported to increase neuropsychiatric and behavioural disorders (Johansson et al., 2010; Divan et al., 2012), trigger cardiac rhythm alteration and peripheral arterial pressure instability (Havas, 2013; Saili et al., 2015), induce changes in immune system function (Lyle et al., 1983; Grigoriev et al., 2010; Sannino et al., 2011, 2014) and alter salivary (Augner et al., 2010) and

thyroid (Koyu et al., 2005; Mortavazi et al., 2009; Pawlak et al., 2014) function. There is an urgent need for more study of these diseases or biological alterations in relation to exposure to both ELF- and RF-EMFs.

4. An emerging concern: cognitive and neurobehavioral problems in children

Children, and especially fetuses, are more vulnerable than adults for most environmental exposures (Sly and Carpenter, 2012). This is because their cells are rapidly dividing and their organ systems are not mature. As a result, events that perturb cellular function early in life can result is abnormalities that last. There is a building body of evidence indicating that exposure to RF-EMFs has adverse effects on cognition and neurobehavior, especially in children and adolescents. Concern about the particular sensitivity of children to RF-EMFs emitted from mobile phone was first raised in 2000 by a British independent expert group (IEG, 2000) that noted that the increased sensitivity to EMFs of children could be due not only to the natural vulnerability of the developing nervous system, but also to the smaller head size and thickness of the skull. These factors, plus the higher conductivity of the young nervous system, result in greater penetration of RF-EMFs into the brain (Gandhi et al., 1996). Of concern is the fact that any adverse effects during development may have life-long consequences and that young people, because they will have a longer life span, will receive a greater cumulative exposure than adults (Kheifets et al., 2005; Hansson Mild et al., 2006).

There are several reasons to be concerned. Animal studies have shown that *in utero* RF-EMF exposure from mobile phones affects fetal programming and leads to alteration in neurodevelopment and behavior of offsprings (Aldad et al., 2012; Zhang et al., 2015). Exposure of young rats to non-thermal intensities impairs learning and spatial memory secondary to a deleterious impact of EMFs on hippocampal, pyramidal or cortical neurons. Similar detrimental cognitive and behavioural defects were also observed in adult animals exposed to low-intensity.

EMFs (Bas et al., 2009; Deshmukh et al., 2015; Kumari et al., 2017; Shahin et al., 2017). The exposure induces markers of oxidative stress and inflammation in the brain (Dasdag et al., 2012; Megha et al., 2015).

There are human data consistent with these animal studies. Divan et al. (2008) reported that prenatal and to a lesser degree postnatal exposure to cell phones is associated with emotional and hyperactivity problems in 7-year old children. This finding was confirmed in a second replicative study involving different participants (Divan et al., 2012). Birks et al. (2017) used data from studies in five cohorts from five different countries (83,884 children) and concluded that maternal mobile phone use during pregnancy increased the risk that the child will show hyperactivity and inattention problems. A meta-analysis involving 125,198 children (mean age 14.5 years) reported statistically significant associations between access to and use of portable screen-based media devices (e.g. mobile phones and tablets) and inadequate sleep quality and quantity and excessive daytime sleepiness (Carter et al., 2016). Early life exposure to lead has long been known to cause a reduction in cognitive function and shortened attention span (Needleman et al., 1979). Two studies have shown that prenatal (Choi et al., 2017) or postnatal (Byun et al., 2017) mobile phone exposure results in greater neurobehavioral effects in children with elevated lead levels than those seen with elevated lead alone. These results raise concern that EMFs may have synergistic actions with other environmental contaminants known to cause a reduction in intelligence quotient (IQ) and attention, such as polychlorinated biphenyls, methyl mercury, environmental tobacco smoke and probably others (Carpenter, 2006).

Finally the problem should be considered at the societal, worldwide level. Many adolescents (Lenhart, 2015) and even very young children and infants (Kabali et al., 2015) use cordless devices immoderately, to such a point that the common intensive use of devices in children and adolescents has been ascribed as an addiction (Paz de la Puente and Balmori, 2007; Roberts et al., 2014).

The specific absorption rate (SAR)-based ICNIRP safety limits were established on the basis of simulation of EMF energy absorption using standardized adult male phantoms, and designed to protect people only from the thermal effects of EMFs. These assumptions are not valid for two reasons. Not only do they fail to consider the specific morphological and bioclinical vulnerabilities of children, but also they ignore the effects known to occur at non-thermal intensities. The same criticisms apply to other so called “independent” advisory groups or agencies, such as the Advisory Group of Non-Ionizing Radiation in the UK (AGNIR, 2012), the French Agency for Food, Environmental and Occupational Health & Safety in France (ANSES, 2013), and the Scientific Committee on Emerging Newly Identified Health Risk (SCENIHR, 2009), all of whom deny the detrimental health effects of low intensity, non thermal EMF exposure and make recommendations based only on thermal SAR considerations.

Although several scientific authorities, such as the US American Academy of Pediatrics (AAP, 2013), and the Russian National Committee on Non-Ionizing Radiation Protection (RNCNIRP, 2011) have made specific recommendations to not allow the use of mobile phones by children and to limit their use by adolescents, unfortunately these age categories remain a target for marketing of mobile phone devices [http://www.who.int/peh-emf/project/mapnatreps/RUSSIA%20report%202008.pdf]. The RNCNIRP has warned that if no rational, health-based safety limits are adopted for children and adolescents and no measures are taken to limit the use of cordless devices, we can expect disruption of memory, decreases in learning and cognitive capabilities, increases in irritability, sleep disturbance, and loss of stress adaptation in this population. There will also be long-term effects, including an increase in brain cancer, infertility, EHS, Alzheimer disease and other neurodegenerative diseases (RNCNIRP, 2011; Markov and Grigoriev, 2015). National and international bodies, particularly the WHO, will bear major responsiblity for failing to provide specific science-based guidance and recommendations so as to avoid such global health threats.

5. Electrohypersensitivity, microwave illness or idiopathic environmental intolerance attributed to electromagnetic fields

There is a segment of the human population that is unusually intolerant to EMFs. The term “electromagnetic hypersensitivity” or “electrohypersensitivity (EHS)” to describe the clinical conditions in these patients was first used in a report prepared by a European group of experts for the European Commission (Bergqvist et al., 1997). Santini et al. (2001, 2003) reported similar symptoms occurring in users of digital cellular phones and among people living near mobile phone base stations.

In 2004, because of the seemingly increasing worldwide prevalence, WHO organized an international scientific workshop in Prague in order to define and characterize EHS. Although not acknowledging EHS as being caused by EMF exposure, the Prague working group report clearly defined EHS as “a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic or electromagnetic fields” (www.who.int/pehemf/EHS_Proceedings_June2006.pdf). Following this meeting, WHO acknowledged EHS as an adverse health condition (WHO, 2005).

According to the Prague Workshop recommendations, it was proposed to use the term “idiopathic environmental intolerance (IEI) attributed to electromagnetic fields” (IEI-EMF) because of the lack of a proven causal link with EMF exposure (Hansson Mild et al., 2006). This pathological disorder is identical to what has been previously described under the term “microwave illness” (Carpenter, 2015).

This syndrome is characterized by fatigue, chronic pain and impaired cognitive function (see the Paris appeal, http://appel-de-paris.com/?lang=en). The precise mechanism(s) whereby environmental exposure to either ELF- or RF-EMFs can cause the development of this syndrome are still uncertain. However several lines of experimental and clinical data are sufficiently strong so as to indicate that ELF-EMFs and RF-EMFs exposure is associated with adverse biological and clinical health effects in humans as well as animals (Rea et al., 1991; McCarty et al., 2011; Belpomme et al., 2015; Hedendahl et al., 2015; Irigaray et al., 2018a). The prevalence of EHS has been estimated to range 1–10% in developed countries (Hallberg and Oberfeld, 2006) but appears today to be around 3% (Huang et al., 2018).

Since WHO official reports on mobile phone exposure and public health (WHO, 2014) and more particularly on EHS (WHO, 2005), much clinical and biological progress has been made to identify and objectively characterize EHS, as was summarized during the international scientific consensus meeting of the 5th Paris Appeal Congress that took place in May 2015 in Brussels at the Royal Belgium Academy of Medicine (ISD, 2015). EHS has many characteristics in common with other IEI pathological disorders, including chronic fatigue syndrome, fibromyalgia, Gulf War Illness and especially the syndrome of multiple chemical senssitvity (MCS), which Belpomme et al. (2015) have shown to be associated with EHS in many patients who report being electrohypersensitive.

5.1. Bioclinical identification and characterisation of electrohypersensitivity

In a prospective study involving systematic face-to-face questionnaire-based interviews and clinical physical examinations of nearly two thousand patients who self-reported having EHS or EHS and MCS, Belpomme and colleagues reported that EHS is a well-defined clinico-biological entity, characterized by the progressive occurrence of neurologic symptoms, including headache, tinnitus, hyperacusis, superficial and/or deep sensibility abnormalities, fibromyalgia, vegetative nerve dysfunction and reduced cognitive capability. These symptoms are repeatedly reported by the patients to occur each time they are exposed to EMFs, even of weak intensity. They result in chronic insomnia, fatigue, emotional lability and depressive tendency (Belpomme et al., 2015; Irigaray et al., 2018b).

Table 4 presents the detailed symptomatic picture which was obtained during face-to-face interviews with subjects with EHS in comparison to those with both EHS and MCS and to a series of apparently healthy control subjects that showed no evidence of EHS and/or MCS. As shown in the Table, the symptoms reported are consistent with those in other published questionnaire-based studies of EHS patients (Dodge, 1970; Johansson et al., 2010; Nordin et al., 2014; Medeiros and Sanchez, 2016; Röösli, 2008). The clinical symptoms observed in EHS or EHS/MCS patients are statistically significantly much more frequent that those in apparently normal controls. Although many of these symptoms are non-specific, the general clinical picture resulting from their association and frequency strongly suggests that EHS can be recognized and identified as a specific neurological disorder.

Because of the multiple and relatively common symptoms and the lack of recognized objective diagnosis criteria, studies on EHS were left with only the patient's self-reported interpretation for many years. As a result, EHS has unfortunately been considered to be a psychiatric disease of unknown origin. This helps explain why most mainstream public health and societal bodies claim there is not sufficient data proving that the clinical symptoms experienced and reported by EHS patients are caused by EMF exposure. Therefore they refuse to acknowledge EHS as a true neuropathological disorder. This negative point of view was supported by some blind or double blind studies showing that most individuals who report they suffer from EHS were not able to identify when they were exposed to either EMFs or sham controls (Rubin et al., 2011; Eltiti et al., 2015). However other studies have found that EHS subjects can identify EMF exposure in a statistically significant manner when they are blinded to whether or not the exposure was on (Rea et al., 1991; McCarty et al., 2011).

To account for these seemingly negative results a nocebo effect was suggested (ANSES, 2017). However there is presently no consensus on a biological mechanism through which a nocebo effect could occur (Medeiros and Sanchez, 2016; Chrousos and Gold, 1992; Jakovljevic, 2014). Moreover, results obtained in a carefully designed psycho-clinical study in self-reporting EHS patients are not consistent with an initial nocebo response to perceived EMF exposure, even though it is plausible that after the onset of the disease such phenomena may intervene secondarily through an acquired learning and conditioning process (Dieudonné, 2016). In addition, a meta-analysis of cross sectional studies has documented a 38% greater risk of development of headaches among mobile phone users than non-users, and an increasing risk of headache with longer daily call duration (Wang et al., 2017).

Belpomme, Irigaray and colleagues recently identified several biomarkers in EHS and/or MCS patients which allow physicians to identify and objectively characterize EHS as a true somatic pathological disorder, discounting the hypothesis of a causal psychosomatic or nocebo-related process. These came in part from a prospective clinical and biological analysis of a series of several hundred consecutive cases of individuals who self-reported that they suffered from EHS or both EHS and MCS (Belpomme et al., 2015) and more recently from the prospective anlaysis of an additional series of EHS patients (Irigaray et al., 2018a). Table 5 summarizes the different biomarkers that have been measured in the peripheral blood of these patients and the results which have been obtained based on the EHS and EHS/MCS patient groups. Note that among the different markers, the 6-hydroxymelatonin sulfate/creatinine ratio in urine appears to be the best marker to be used in medical practice since it has been found to be decreased in all cases evaluated to date (Belpomme et al., 2015).

By measuring different major oxidative stress-related biomarkers, such as thiobarbituric acid reactive substances (TBARS), oxided glutathione (GSSG) and nitrotyrosine (NTT) in EHS patients, Irigaray et al. (2018b) have recently shown that near 80% of the EHS patients present with detectable oxidative stress biomarkers (Fig. 1). More than 40% of EHS patients present with at least one positive biomarker, 20% with two and 15% will all three of the biomarkers investigated. This indicates that in addition to the inflammation-related biomarkers previously associated with EHS, EHS patients are also characterized by exhibiting biomarkers of oxidative stress (Belpomme et al., 2015; Irigaray et al., 2018a,b).

The significance of the different biomarkers measured in the peripheral blood of EHS and EHS/MCS patients is that these results imply that these patients present with some degree of oxidative/nitrosative stress, inflammation and autoimmune response. Increased levels of several of these markers (notably protein S100B and NTT) may reflect hypoxia-associated oxidative stress-induced blood brain barrier (BBB) opening. It has been previously hypothesized that opening of the BBB can be caused by environmental

Table 4
Clinical symptom occurrence in EHS and EHS/MCS patients in comparaison with normal controls[a].

	EHS	EHS/MCS	p[b]	Normal controls	p[c]	p[d]
Headache	88%	96%	0.065	0%	<0.0001	<0.0001
Dysesthesia	82%	96%	0.002	0%	<0.0001	<0.0001
Myalgia	48%	76%	<0.0001	6%	<0.0001	<0.0001
Arthralgia	30%	56%	<0.001	18%	0.067	<0.0001
Ear heat/otalgia	70%	90%	<0.001	0%	<0.0001	<0.0001
Tinnitus	60%	88%	<0.0001	6%	<0.0001	<0.0001
Hyperacousis	40%	52%	0.118	6%	<0.0001	<0.0001
Dizziness	70%	68%	0.878	0%	<0.0001	<0.0001
Balance disorder	42%	52%	0.202	0%	<0.0001	<0.0001
Concentration/Attention deficiency	76%	88%	0.041	0%	<0.0001	<0.0001
Loss of immediate memory	70%	84%	0.028	6%	<0.0001	<0.0001
Confusion	8%	20%	0.023	0%	0.007	<0.0001
Fatigue	88%	94%	0.216	12%	<0.0001	<0.0001
Insomnia	74%	92%	0.001	6%	<0.0001	<0.0001
Depression tendency	60%	76%	0.022	0%	<0.0001	<0.0001
Suicidal ideation	20%	40%	0.003	0%	<0.0001	<0.0001
Transitory cardiovascular abnormalities	50%	56%	0.479	0%	<0.0001	<0.0001
Occular deficiency	48%	56%	0.322	0%	<0.0001	<0.0001
Anxiety/Panic	38%	28%	0.176	0%	<0.0001	<0.0001
Emotivity	20%	20%	1	12%	0.176	0.176
Irritability	24%	24%	1	6%	<0.001	<0.001
Skin lesions	16%	45%	<0.0001	0%	<0.0001	<0.0001
Global body dysthermia	14%	8%	0.258	0%	<0.0001	<0.007

[a] This data results from the clinical analysis of the 100 first clinically evaluated cases issued from the already published series of EHS and/or MCS patients who have been investigated for biological markers [Belpomme et al., 2015]. It has been compared symptomatically with data obtained from a series of 50 apparently normal subjects matched for age and sex, used as controls.
[b] Significance levels (p values) obtained for compararison between the EHS and EHS/MCS groups.
[c] Significance levels (p values) obtained for compararison between the EHS and normal control groups.
[d] Significance levels (p values) obtained for compararison between the EHS/MCS and normal control groups.

Table 5
Patient mean values and standard deviations of biomarker levels in comparison with normal reference values as well as the percentage of patients with abnormal values in the peripheral blood in subjects with EHS or both EHS and MCS (Belpomme et al., 2015).

Biomarker and Normal reference values	Patients groups			
	EHS Mean ± SD	% Above normal	EHS/MCS Mean ± SD	% Above Normal[a]
hs-CRP < 3 mg/l	10.3 ± 1.9	15%	6.9 +/1.7	14.3%
Vitamine D > 30 ng/ml	20.6 ± 0.5	69.3%	14.5 ± 1.3	70.1%
Histamine< 10 nmol/l	13.6 ± 0.2	37%	13.6 ± 0.4	41.5%
IgE< 100 UI/ml	329.5 ± 43.9	22%	385 ± 70	24.7%
S100B < 0.105 μg/l	0.20 ± 0.03	14.7%	0.17 ± 0.03	19.7%
Hsp 70 < 5 ng/ml	8.2 ± 0.2	18.7%	8 ± 0.3	25.4%
Hsp 27< 5 ng/ml	7.3 ± 0.2	25.8%	7.2 ± 0.3	31.8%
Anti-O-myelin auto-antibodies[b]	Positive	22.9%	Positive	23.6%
24-h urine 6-OHMS/creatinine ratio >0.8[c]	0.042 ± 0.003	100%	0.048 ± 0.006	100%

hs-CRP, high-sensitivity C-reactive protein; IgE, Immunoglobulin E; S100B, S 100 calcium binding protein B; Hsp 27, heat shock protein 27; Hsp 70, heat shock protein 70; anti-O-myelin auto-antibodies, auto-antibodies against O-myelin; 6-OHMS, 6-hydroxymelatonin sulfate.
[a] There is no statistically significant difference between the two groups of patients for the different biomarkers analyzed, suggesting that EHS and MCS share a common pathological mechanism for genesis.
[b] Qualitative test.
[c] Data restricted to those not on neuroleptic medication as the simultaneous use of several psychotherapeutic drugs may also be associated with a decrease of this 24-h urine ratio by modifying melatonine metabolism.

stressors, be they chemicals or EMFs. This may have occurred in these patients, as has been shown to occur in several (but not all) animal experiments involving EMF exposure (Oscar and Hawkins, 1977; Persson et al., 1997; Eberhardt et al., 2008; Sirav and Seyhan, 2009). Comparable data using metabolic and genetic biomarkers were also obtained in another large series of EHS patients (De Luca et al., 2014). Overall these data indicate that the clinical use of biomarkers allows the objective characterisation and identification of EHS and MCS as two etiopathologic facets of a unique pathological disorder, and also allows insight into the genesis of these two diseases.

The development of new imaging techniques has also greatly increased our ability to objectively characterize EHS and MCS. Using ultrasonic cerebral tomosphygmography (UCTS) (Parini et al., 1984), EHS- and EHS/MCS-patients were found to have a statistically significant decrease in mean pulsometric index in several middle cerebral artery-dependant portions of the temporal lobes, especially in the capsulo-thalamic area, which is part of the limbic

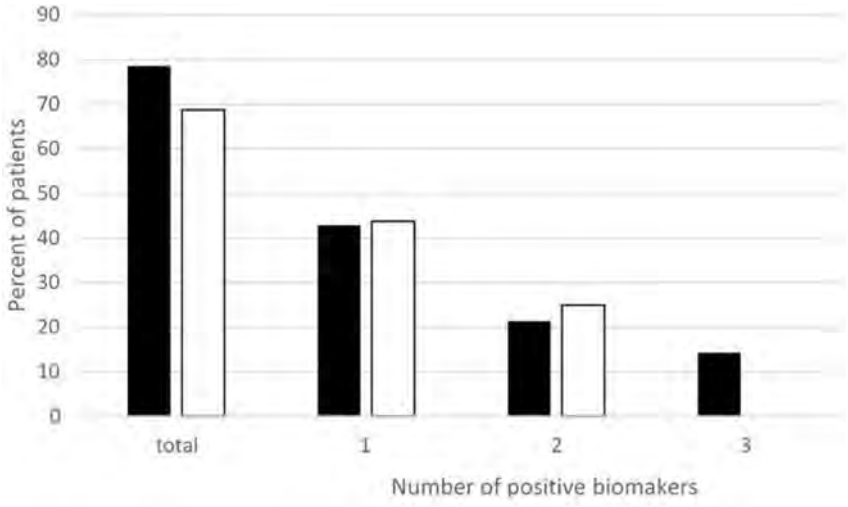

Fig. 1. Percentage of EHS self-reporting patients having positive TBARs, GSSG and/or NTT oxidative stress biomarkers measured in the peripheral blood. "Positive" biomarkers correspond to marker levels above the upper normal limit; "total" corresponds to the patients with one or more positive biomarker levels. Black bars show the percentage of patients with one, two or all three of the biomarkers for TBARS, GSSG and NTT. The white bars show the percentage of patients with either TBARs or GSSG or both oxidative stress markers.

system and the thalamus. This suggests that EHS and EHS/MCS may be associated with a brain blood flow (BBF) deficiency and/or neuronal dysfunction in these brain structures (Belpomme et al., 2015; Irigaray et al., 2018a,b). Irigaray et al. (2018c) have recently confirmed that UCTS is the best imaging technique to diagnose EHS and to follow patients treated for EHS and/or MCS.

In addition, using positron emission tomography (PET) it has been shown that short term exposure to pulse-modulated RF-EMF causally affects regional BBF in normal subjects using a mobile phone (Aalto et al., 2006; Huber et al., 2005), a finding that may account for the modifications observed in the sleep and waking EEG (Huber et al., 2002). By use of functional MRI (fMRI) in EHS patients exposed chronically to ELF-EMFs, regional BBF changes have been reported in the frontal lobes, such as abnormal default mode network and more particularly a decrease in BBF and cerebral metabolism. These observations indicate that fMRI may also be a tool for diagnosis of EHS and clinical follow up of patients (Heuser and Heuser, 2017). A decreased BBF-associated pulsometric index decrease in both hemispheres was also recently observed by the Belpomme group by using transcranial Doppler ultrasound (TDU) (Purlauastja and Sorond, 2012) applied to the middle cerebral artery in a study involving 120 EHS and/or MCS patients. This study revealed a decrease in pulsatility index and an increase in diastolic flow velocity in 70% of the 120 cases investigated to date.

In summary it is the strong opinion of the authors that there is presently sufficient clinical, biological and radiological data emanating from different independent international scientific research groups for EHS, whatever its causal origin, to be acknowledged as a well-defined, objectively characterized pathological disorder. As a result, patients who self-report that they suffer from EHS should be diagnosed and treated utilizing presently available objective biological tests, among which are the concentration of peripheral blood biomarkers and the use of imaging techniques such as PET, fMRI and TDU and, when available, UCTS. Whatever its etiological origin and mechanism of action, EHS should be acknowledge by the WHO as a real and distinct neurological and pathological disorder (McCarty et al., 2011; Hedendahl et al., 2015) and thus be included in the International Classification of Diseases.

5.2. Possible etiopathogenic processes involved in genesis of electrohypersensitivity

EMFs, both RF-EMFs at non-thermal intensities and ELF-EMFs, have been found to cause persistent adverse biological effects in microorganisms (Fojt et al., 2004), plants (Roux et al., 2008; Maffei, 2014), birds (Balmori, 2005; Balmori and Hallberg, 2007; Frey, 1993), and mammals. Therefore the effects observed in humans cannot be due to only a nocebo or psychosomatic effect. These biological effects may be due both to the pulsed and polarised characteristics of man-made EMFs emitted by electric or wireless technologies as opposed to the terrestrial non-polarised and continuously emitted natural EMFs (Blackman, 2009; Belyaev, 2015; Panagopoulos et al., 2015).

The inflammatory and oxidative/nitrosative states that have been documented in EHS patients are remarkable since they confirm the data obtained experimentally in animals exposed to non-thermal EMFs (Esmekaya et al., 2011; Burlaka et al., 2013), and especially in the brain (Megha et al., 2015; Kesari et al., 2011). The limbic system–associated capsulo-thalamic abnormalities that the Belpomme group has observed by using UCTS in EHS and/or MCS patients (Belpomme et al., 2015; Irigaray et al., 2018a,c) may likely correspond to the hippocampal neuronal alterations caused by EMF exposure in the rats (Bas et al., 2009; Furtado-Filho et al., 2015; Deshmukh et al., 2013). Fig. 2 summarizes our hypothesis regarding the inflammation and oxidative stress-related mechanisms which may account for EMF- and/or chemically-related health effects in the brain and consequently for EHS genesis.

6. Mechanisms whereby low intensity electromagnetic fields cause biological effects and harm

Arguments used in the past to attempt to discount the evidence showing deleterious health effects of ELF-EMFs and RF-EMF exposure at non-thermal SAR levels were based on the difficulties encountered in understanding the underlying biological effects and the lack of recognized basic molecular mechanisms accounting for these effects. This is no longer the case. There are a number of well-documented effects of low intensity EMFs that are the mechanistic basis behind the biological effects documented above (www.

bioinitiative.org). These include induction of oxidative stress, DNA damage, epigenetic changes, altered gene expression and induction including inhibition of DNA repair and changes in intracelluar calcium metabolism. Both low-intensity ELF-EMF and non-thermal RF-EMF effects depend on a number of physical parameters and biological variables and physical parameters, which account for the variation in health outcomes (Belyaev, 2015; Belyaev et al., 1999). Importantly, the most severe health effects are observed with prolonged chronic exposures even when intensities are very low (Belyaev, 2017). The physics of non-equilibrium and non-linear systems and quantum mechanics are at least in part the basis of the physical mechanisms responsible for the non-thermal molecular and biological effects of non-thermal EMF radiation (Belyaev, 2015), although a detailed report on these actions is beyond the scope of this review.

Lower RF-EMF intensity is not necessarily less bioactive or less harmful. Non-thermal EMF effects can be observed at intensities which are very close to ordinary background levels and quite similar to intensities emitted by mobile phone base stations. There are time windows for observation of non-thermal EMF effects which may be dependent upon the endpoint measured, the cell type and the duration and power density of exposure. Non-thermal RF-EMF effects are affected by static magnetic fields and electromagnetic stray fields, which result in the variation of non-thermal EMF effects from mobile phones because of adjacent electrical appliances, power lines and other sources of ELF and static magnetic fields, including changes in the geomagnetic field (Gapeev et al., 1999a and b).

Cell-to-cell interactions potentiate the response to non-thermal EMFs (Belyaev et al., 1996). Biological responses to EMFs have been shown to be influenced by sex and age (Zhang et al., 2015; Sirav and Seyhan, 2016). Physiological parameters such as the stage of cell growth, oxygen, divalent ions and temperature are important variables affecting cellular responses to EMFs (Liburdy and Vanek, 1987; Sannino et al., 2011).

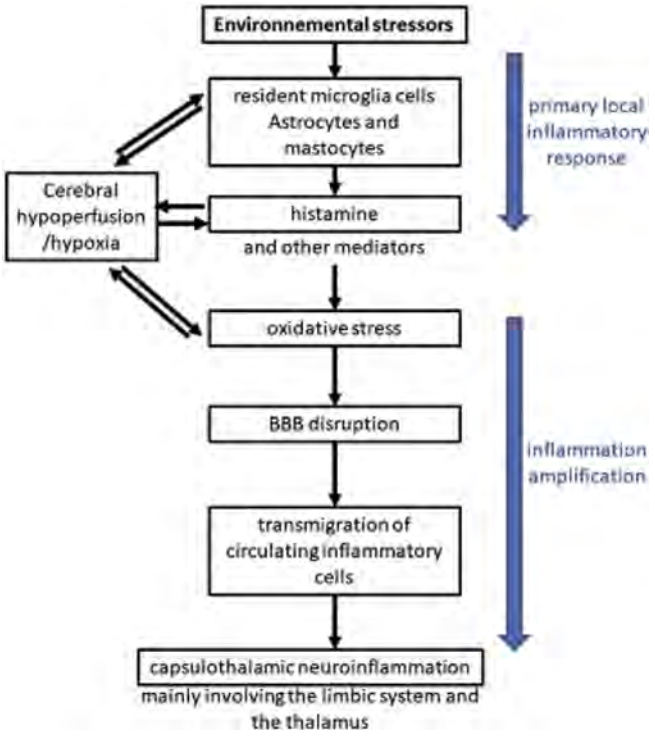

Fig. 2. Hypothetical EHS/MCS common etiopathogenic model based on neuroinflammation and oxidative/nitrosative stress-induced blood brain barrier disruption (Belpomme et al., 2015).

6.1. Combined exposures

EMFs at non-thermal intensities may interfere with other environmental stressors, showing an interplay of molecular pathways and resulting in either beneficial or detrimental health effects, depending on the nature and conditions of co-exposures (Novoselova et al., 2017; Ji et al., 2016). One example is the demonstration that RF-EMF exposure modulates the DNA damage and repair induced by ionizing radiation (Belyaev et al., 1993). Another example is the synergistic of exposure to lead and EMFs on cognitive function in children described above (Choi et al., 2017; Byun et al., 2017). These co-exposure factors should be considered when assessment of detrimental effects, including carcinogenicity, is performed.

Not all of the effects of EMFs on the nervous system and other organs are necessarily harmful. The best example of a positive effect is the well-documented and clinically useful benefit of applied magnetic fields to promote bone healing (Bassett, 1994). Both ELF-EMF (Zhang et al., 2015) and RF-EMF (Arendash et al., 2010) have been reported to slow cognitive decline in rodent models of Alzheimer's disease. Some human studies report a facilitating effects of cognitive performance (Lee et al., 2001) while Koivisto et al. (2000) reported an increase in response time and vigilance tasks but a decrease in mental arithmetic tasks. These studies clearly show that EMFs have biological effects at non-thermal intensities, but suggest that not all biological effects are necessarily harmful.

6.2. Duration of exposure and dose intensity

Such parameters as power density, dose, and duration of exposure have been analyzed for development of reliable safety standards, which would protect against the detrimental health effects of chronic exposure to RF-EMFs at non-thermal intensities. Some studies show no effect under fixed short-term exposures, but this does not imply that there are no effects from longer-term exposures (Choi et al., 2014). Exposure in studies showing RF-EMF effects was on average twice the duration as those with no significant effects (Cucurachi et al., 2013). The response to non-thermal EMFs depends on both power density and duration of exposure. Importantly, the same response is observed with lower power density but prolonged exposure as at higher power density and shorter exposure (Nordenson et al., 1994). While SAR is a good surrogate for thermal RF effects from acute exposures, many studies have shown that SAR should be either replaced by “dose-specific absorption” or power density complimented by duration of exposure for description of non-thermal RF effects (Belyaev, 2015). Recent studies have provided more evidence for the greater importance of dose and duration of exposure than SAR alone for biological and health effects from long-term exposures to non-thermal RF-EMFs (Furtado-Filho et al., 2015).

6.3. Oxidative stress

Non-ionizing radiation does not have sufficient energy to directly break chemical bonds, and therefore the DNA damage that occurs with non-ionizing EMF exposures is primarily a consequence of generation of reactive oxygen species (ROS), resulting in oxidative stress. There are numerous animal experiments which clearly demonstrate that non thermal EMFs can cause oxidative stress (Esmekaya et al., 2011; Burlaka et al., 2013), particularly in the brain (Shahin et al., 2017; Dasdag et al., 2012; Megha et al., 2015; Furtado-Filho et al., 2015). Oxidative stress is known to

play a central role in development of cancer and aging and serves as a signaling agent in the inflammatory response (Holmstrom and Finkel, 2014).

The brain is a particularly important organ for sensitivity to EMFs. Brain cancer resulting from EMF exposures is a serious concern, and EHS is a disease of the central nervous system. Several mechanisms at the cellular and molecular levels have been reported that may be the basis of these non-thermal RF-EMF effects on brain function. ELF- and/or RF-EMF exposure at embryonic or early postnatal stages can alter *in vivo* synaptic efficacy and plasticity of neurons (Balassa et al., 2014), a finding which was further supported by *in vitro* studies showing a significant decrease in the differentiation of neural stem cells into neurons (Eghlidospour et al., 2017), the alteration of transcript levels of neuronal differentiation-related genes and impairment of neurite outgrowth of embryonic neural stem cells exposed to ELF- or RF-EMFs (Ma et al., 2014). These observations support the conclusion that low-intensity but prolonged exposure to non-thermal EMFs may have adverse effects on neurogenesis during development and indicate how important it is to protect the fetus and young child from excessive exposure to all mobile devices.

Animal studies have documented that 900 MHz or 2.45 GHz non thermal RF-EMF exposure in rats, either short term or chronic, can trigger neuronal dysfunction and even apoptosis of hippocampal pyramidal cells (Bas et al., 2009; Shahin et al., 2017) and cerebellum Purkinje cells (Sonmez et al., 2010) through induction of oxidative stress. Exposure of pregnant dams elicited EMF oxidative stress-induced neuronal pathologic changes in offspring (Odaci et al., 2016). Such pathological changes could be due to ROS-induced opening of the BBB (Nordal and Wong, 2005) and/or to ROS-associated brain hypoxia caused by a decrease in EMF-induced BBF and/or EMF-induced hemoglobin deoxygenation (Mousavy et al., 2009; Muehsam et al., 2013). The resulting hypoxia may induce metabolic neuronal dysfunction as in the case of EHS patients (Belpomme et al., 2015) but also neuronal cell death by either apoptosis or necrosis as in the case of Alzheimer's disease and other forms of dementia (Bell and Zlokovic, 2009).

While some consider the laboratory data on EMFs as being inconsistent, showing either detrimental or no effects and on occasion even beneficial effects, the vast majority still show detrimental effects. For example Henry Lai in the Bioinitiative Report Research Summaries Update of November 2017, Chapter 6 on Genotoxic Effects, reported that i) of 46 studies on ELF genotoxicity with the comet assay as the end point, 34 studies (74%) showed detrimental effects, ii). Of 189 total studies on ELF and oxidative stress, 162 (87%) showed a positive correlation, and iii) of 200 studies on RF and free radicals, 180 (90%) showed detrimental effects. One reason for variability between laboratory studies is the strong dependence on low-threshold EMF effects on a number of physical and biological variables (Belyaev, 2010).

6.4. Genetic and epigenetic mechanisms

Genetic effects are the most direct cause for carcinogenicity. This is true both for genotoxic changes caused by exposure to EMFs and existing polymorphic genetic differences within a population that increase susceptibility to cancer. DNA can no longer be considered to be unaffected by environmental EMF levels, as many studies have shown that DNA can be activated and damaged by EMFs at levels that have been considered to be safe (Blank and Goodman, 1999).

The primary mechanism through which low-intensity EMFs can alter DNA is through ROS production. Lai and Singh (2004) first reported that a 2 h exposure of rats to 60 Hz EMFs at 0.1–0.5 mT resulted in DNA strand breaks in neurons, and provided evidence that this effect was mediated by free radical formation and blocked by free radical scavengers. Vijayalaxmi and Prihoda (2009) in a meta-analysis of 87 publications found a biologically small but statistically significant difference between DNA damage in ELF-EMF-exposed somatic cells as compared to controls, and reported evidence for epigenetic changes for some outcomes. For ELF-EMFs this breakage effect was stronger when exposure was intermittent rather than continuous (Nordenson et al., 1994).

Yang et al. (2008) have reported an OR = 4.31 (95% CI = 1.54–12.08) for leukemia in children living within 100 m of a high voltage powerline if they had a certain polymorphism of a DNA repair gene.

Exposure to RF-EMFs can also induce DNA damage under specific conditions (Markova et al., 2005). Tice et al. (2002) and Vijayalaxmi et al. (2013) reported DNA damage and micronuclei formation in cultured human leukocytes and lymphocytes upon exposure to RF-EMF signals of at least 5 W/kg. Not all cell types showed similar responses. Schwartz et al. (2008) reported micronucleus changes in fibroblasts but not lymphocytes exposed to 1950 MHz EMFs. Kesari et al. (2014) also demonstrated DNA strand breaks in the brains of rats exposed for 2 h per day for 60 days to a 3G mobile phone. Changes in DNA secondary structure (Semin, 1995; Diem et al., 2005) and chromosome instability (Mashevich, 2003) have been observed upon exposure to RF-EMFs emitted by mobile phones.

Epigenetic changes, rather than genetic changes in DNA, may underlie many or even most of the biological effects of non-thermal EMFs (Sage and Burgio, 2017). Non-thermal EMFs are epigenetic stressors which can alter gene expression by acting through physical or biochemical processes and be reflected as chromatin remodeling (Belyaev et al., 1997), histone modification (Wei et al., 1990) or altered microRNA (Dasdag et al., 2015) at intensities far below those that cause measureable tissue heating.

Chromatin plays a key regulatory role in controlling gene expression and, more particularly, the access of transcription factors to DNA. It has been shown that extremely low intensity RF-EMF exposure, i.e. at intensities comparable to that of mobile phone and towers, results in changes in chromatin conformation and gene expression (Belyaev et al., 1997; Belyaev and Kravchenko, 1994; Belyaev et al., 2006; Belyaev et al., 2009). In a large number of cells and tissues, compaction of chromatin in specific loci may lead to gene silencing, loss of histone regulatory effects and DNA repair capacity (Wei et al., 1990). Belyaev and collaborators (Markova et al., 2005; Belyaev et al., 2009) have shown that exposure to RF-EMFs emitted by GSM mobile phone alters chromatin conformation in human lymphocytes and inhibits formation of p53-binding protein 1 (53BP1) and phosphorylated histone H2AX (γ-H2AX) DNA repair foci.

EMFs in both the ELF and RF ranges may epigenetically affect DNA by inducing the expression of stress response genes and consequently the synthesis of chaperone stress proteins (Blank and Goodman, 2011a and b). A specific gene sequence has been identified that acts as a sort of antenna, specifically sensitive and responsive to EMFs (Blank and Goodman, 2011b). This is a gene sequence coding for HSP70, a protein belonging to a family of conserved, ubiquitously expressed “heat shock proteins” that sense danger signals and protect cells from the most disparate stress conditions. This is an unambiguous demonstration that EMF exposure even at non-tissue heating intensities has the potential to be harmful to cells and organisms. The HSP70 promotor contains different DNA regions that are specifically sensitive to diverse stressors, thermal and non-thermal. The EMFs are specifically perceived by the sequences sensitive to non-thermal stimuli. During the process of HSP70-response induction, EMFs can activate directly the HSP70 gene promoter (Rodrequez-De la Fuente et al.,

2010) which contains a magnetic field-responsive domain (Lin et al., 1999, 2001).

EMF-related HSP70 and HSP27 stress responses have been detected in the hippocampus of rats exposed to non-thermal EMFs (Yang et al., 2012). Shahin et al. (2017) reported that mice exposed to 2G mobile phones continuously for four months showed elevated ROS, lipid peroxidation, total nitrate and nitrite concentrations and malondialdehyde levels in homogenates of different tissues, and decreased levels of several antioxidant enzymes. These observations justify the use of these markers to characterize EHS in patients who report that they are sensitive to EMFs.

The EMF effects have been suggested to be mediated by the mitogen-activated protein kinase (MAPk) cascades, which is a central signaling transduction pathway which governs all stress-related cellular processes occurring in response to extracellular stimuli (Friedman et al., 2007). It has been shown that long term exposure of cells to mobile phone frequencies or to ELF-EMFs (Goodman et al., 2009) activates the extracellular-signal regulated kinase (ERK), which is one of the four MAPk cascades so far identified.

Non-thermal RF-EMFs may also alter expression of other genes. As long ago as Byus et al., 1988 showed that 450 MHz RF increased ornithine decarboxylase activity in hepatoma cells. Markova et al. (2005) exposed human fibroblasts and mesenchymal stem cells to mobile phone RF-EMFs with analysis of tumor suppressor p53 binding protein 1. Formation of 53BP1 foci was inhibited in both cells types, but the stem cells always showed a greater response. Fragopoulou et al. (2011) exposed mice to either a typical mobile phone or a wireless DECT base station and analyzed the brain proteome. They found significant alteration in 143 specific proteins (ranging from a 0.003 fold downregulation to up to a 114-fold overexpression.) Luo et al. (2013) exposed pregnant women undergoing a first trimester abortion to a mobile phone applied to the abdomen and performed a proteomic analysist of placental villous tissue. They report 15 proteins which were significantly altered by at least 2- to 2.5-fold in exposed women as compared to control women. Twelve of these proteins were identified. Yan et al. (2008) exposed rats to mobile phones 6 h per day for 126 days, and found upregulation of specific mRNAs that regulated several proteins, including calcium ATPase, neural cell adhesion molecule, neural growth factor and vascular endothelial growth factor. EMFs at non thermal levels may not only alter the expression of many proteins but also may directly affect protein conformation (Fragopoulou et al., 2011; Bohr and Bohr, 2013; Beyer et al., 2013) and modify enzyme activity (Vojisavljevic et al., 2010), so altering the regulating capacity of the epigenome. These are epigenetic, not genetic, effects (Sage and Burgio, 2017).

Non-thermal EMF exposure can epigenetically interfere with the differentiation and proliferation programs of stem cells in fetal and adult tissues through ROS production (Wolf et al., 2007; Falone et al., 2007; Ayşe et al., 2010; Park et al., 2014). Stem cells are the most sensitive cells to EMF exposure (Eghlidospour et al., 2017; Markova et al., 2010) and this is particularly the case for neural stem cells of the hippocampus (Leone et al., 2014).

The endogenous natural ionic currents and electrical fields in the human body (Jaffe and Nuccitelli, 1977) are vulnerable to the oscillary properties of non-thermal EMFs. These consequently may cause detrimental effect on cell differentiation and proliferation in adult tissues (Levin, 2003) in addition to the effects on cell differentiation, proliferation and migration in the fetus (Wolf et al., 2007; Ayşe et al., 2010; Leone et al., 2014). Fetal programming cannot be reduced to only genetic programs. Developmental processes are essentially epigenetic (Leone et al., 2014), and exposure to epigenetic stressors such as non-thermal EMFs are much more dangerous for the fetus than for the adults.

6.5. Calcium regulation

There has long been evidence that EMFs alter several aspects of calcium function. This is important because calcium regulates many different aspects of cell function. Bawin and Adey (1976) reported that very weak ELF-EMFs trigger efflux of calcium from isolated chick brain, although the implications of this observation were not clear. Later they reported a similar action of RF-EMFs (Adey et al., 1982). Pulsed low-frequency EMFs promote bone healing and promote calcium uptake into bone (Spadaro and Bergstrom, 2002) and osteoblasts (Zhang et al., 2010). 50 Hz EMFs increase the number of voltage-gated calcium channels in neuroendocrine cells (Grasso et al., 2004) and presynaptic nerve cell terminals (Sun et al., 2016). Wei et al. (2015) found that ELF-EMFs also altered the frequency of calcium transients in cardiomyocytes and decreased calcium concentrations in sarcoplasmic reticulum. These changes in calcium in heart muscle may be the basis for the cardiovascular effects reported in humans on exposure to EMFs (Havas, 2013). In spite of numerous studies reporting altered calcium metabolism upon exposure to both ELF- and RF-EMFs, the overall implications of these effects are still not clear. However, some have suggested (Ledoigt and Belpomme, 2013) that calcium activation of proteins could be the initial event that results in altered protein configuration, leading to generation of ROS and ultimately activating the molecular pathways to cancer.

7. Public Health Implications of Human Exposure to EMFs

The incidence of brain cancer in children and adolescents has increased between 2000 and 2010 (Ostrom et al., 2015). Gliomas are increasing in the Netherlands (Ho et al., 2014), glioblastomas are increasing in Australia (Dobes et al., 2011) and England (Philips et al., 2018) and all brain cancers are increasing in Spain (Etxeberrua et al., 2015) and Sweden (Hardell and Carlberg, 2017). The latency period between initial exposure and clinical occurrence of brain cancer is not known but is estimated to be long. While not all reports of brain cancer rates show an increase, some do. The continually increasing exposure to EMFs from all sources may contribute to these increases. The prevalence of EHS is unknown, but various reports suggest that it is between 1 and 10% of the population (Hallberg and Oberfeld, 2006; Huang et al., 2018). Male fertility has been declining (Geoffroy-Siraudin et al., 2012; Levine et al., 2017). EMFs increase the risk of each of these diseases and others. Alzheimer's disease is increasing in many countries worldwide and its association with ELF-EMF occupational exposure has been clearly demonstrated through several independent epidemiological studies (Davanipour and Sobel, 2009; Sobel et al., 1996; Qiu et al., 2004) and a meta-analysis of these studies (García et al., 2008). A recent meta-analysis (Huss et al., 2018) has reported an increased risk of amyotrophic lateral sclerosis in workers occupationally exposure to ELF-EMFs.

Safety limits for RF exposure have been based (until today) on the thermal effects of EMFs. But these standards do not protect people, particularly children, from the deleterious health effects of non-thermal EMFs (Nazıroğlu et al., 2013; Mahmoudabadi et al., 2015). Each of these diseases is associated with decrements in health and quality of life. Brain cancer patients often die is spite of some improvement in treatment, while EHS patients present with increased levels of distress, inability to work, and progressive social withdrawal. The ability for humans to reproduce is fundamental for the maintenance of our species.

The scientific evidence for harm from EMFs is increasingly strong. We do not advocate going back to the age before electricity or wireless communication, but we deplore the present failure of public health international bodies to recognize the scientific data

showing the adverse effects of EMFs on human health. It is encouraging that some governments are taking action. France has removed WiFi from pre-schools and ordered Wi-Fi to be shut off in elementary schools when not in use (http://www.telegraph.co.uk.news/2017/12/11/france-ipose-total-ban-mobile-phones-schools/). The State of California Department of Public Health has issued a warning on use of mobile phones and offered advice on how to reduce exposure (State of California, 2017). There are many steps that are neither difficult nor expensive that can be taken to use modern technology but in a manner that significally reduces threats to human health.

It is urgent that national and international bodies, particularly the WHO, take this significant public health hazard seriously and make appropriate recommendations for protective measures to reduce exposures. This is especially urgently needed for children and adolescents. It is also important that all parts of society, especially the medical community, educators, and the general public, become informed about the hazards associated with exposure to EMFs and of the steps that can be easily taken to reduce exposure and risk of associated disease.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.envpol.2018.07.019.

References

Aalto, S., Haarala, C., Brück, A., Sipilä, H., Hämäläinen, H., Rinne, J.O., 2006. Mobile phone affects cerebral blood flow in humans. J. Cerebr. Blood Flow Metabol. 26, 885–890.

AAP (American Academy of Pediatrics), 2013. American Academy of Pediatrics Demands FCC Protect Children from Cell Phone & Wireless Radiation. Letter from the American Academy of Pediatrics to the FCC Regarding Radiofrequency Electromagnetic Radiation Standards. Available at: the FCC's web site at. http://bit.ly/17tQclg. http://www.saferemr.com/2013/09/american-academy-of-pediatrics-demands.html.

Adey, W.R., Bawin, S.M., Lawrence, A.F., 1982. Effects of weak amplitude-modulated microwave fields on calcium efflux from awake cat cerebral cortex. Bioelectromagnetics 3, 295–307.

Agarwal, A., Desai, N.R., Makker, K., Varghese, A., Mouradi, R., Sabanegh, E., et al., 2009. Effects of radiofrequency electromagnetic waves (RF-EMW) from cellular phones on human ejaculated semen: an in vitro pilot study. Fertil. Steril. 92, 1318–1325.

AGNIR (Advisory Group of Non-Ionizing Radiation), 2012. Health Effects from Radiofrequency Electromagnetic Fields. Report of the independent advisory group on non-ionising radiation. April 2012.

Ahlbom, A., Day, N., Feychting, M., Roman, E., Skinner, J., Dockerty, J., et al., 2000. A pooled analysis of magnetic fields and childhood leukaemia. Br. J. Canc. 843, 692–698.

Akhavan-Sigari, R., Baf, M.M., Ariabod, V., Rohde, V., Rahighi, S., 2014. Connection between cell phone use, p53 gene expression in different zones of glioblastoma multiforme and survival prognoses. Rare Tumors 2014 (6), 5350. https://doi.org/10.4081/rt.2014.5350.

Aldad, T.S., Gan, G., Gao, X.B., Taylor, H.S., 2012. Fetal radiofrequency radiation exposure from 800-1900 MHz-rated cellular telephones affects neurodevelopment and behavior in mice. Sci. Rep. 2, 312.

ANSES (French Agency for Food, Environmental and Occupational Health & Safely), 2013. Radiofreqences et sante. October 2013.

ANSES (French Agency for Food, Environmental and Occupational Health & Safely), 2017. Hypersensibilite Electromagnetique Ou Intolerance Environmentale Idiopathique Attribuee Aux Champs Electromagnetiques. Pre-rapport du groupe de travail “Radiofrequence et Sante.”).

Arendash, G.W., Sanchez-Ramos, J., Mori, T., Mamcarz, M., Lin, X., Runfeldt, M., et al., 2010. Electromagnetic field treatment protects against and reverses cognitive impairment in Alzheimer's disease mice. J. Alzheim. Dis. 19, 191–210.

Augner, C., Hacker, G.W., Oberfeld, G., Florian, M., Hitzl, W., Hutter, et al., 2010. Effects of exposure to GSM mobile phone base station signals on salivary cortisol, alpha-amylase, and immunoglobulin A. Biomed. Environ. Sci. 23, 199–207.

Ayşe, I.G., Zafer, A., Sule, O., Işil, I.T., Kalkan, T., 2010. Differentiation of K562 cells under ELF-EMF applied at different time courses. Electromagn. Biol. Med. 29, 122–130.

Baan, R., Grosse, Y., Lauby-Secretan, B., El Ghissassi, F., Bouvard, V., et al., 2011. Carcinogenicity of radiofrequency electromagnetic fields. Lancet Oncol. 12, 624–626.

Balassa, T., Varró, P., Elek, S., Drozdovszky, O., Szemerszky, R., Világi, I., et al., 2014. Changes in synaptic efficacy in rat brain slices following extremely low-frequency magnetic field exposure at embryonic and early postnatal age. Int. J. Dev. Neurosci. 31, 724–730.

Balmori, A., 2005. Possible effects of electromagnetic fields from phone masts on a population of white stork (*Ciconia ciconia*). Electromagn. Biol. Med. 24, 109–119.

Balmori, A., Hallberg, O., 2007. The urban decline of the house sparrow (*Passer domesticus*): a possible link with electromagnetic radiation. Electromagn. Biol. Med. 26, 141–151.

Bas, O., Odaci, E., Kaplan, S., Acer, N., Ucok, K., Colakoglu, S., 2009. 900 MHz electromagnetic field exposure affects qualitative and quantitative features of hippocampal pyramidal cells in the adult female rat. Brain Res. 1265, 178–185.

Bassett, A., 1994. Therapeutic uses of electric and magnetidc fields in orthopaedics. In: Carpenter, D.O., Ayrapetyan, S. (Eds.), Biological Effects of Electric and Magnetic Fields, vol. 2, pp. 13–48.

Bawin, S.M., Adey, W.R., 1976. Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequency. Proc. Natl. Acad. Sci. Unit. States Am. 73, 1999–2003.

Bell, R.F., Zlokovic, B.V., 2009. Neurovascular mechanisms and blood-brain barrier disorder in Alzheimer's disease. Acta Neuropathol. 118, 103–113.

Belpomme, D., Campagnac, C., Irigaray, P., 2015. Reliable disease biomarkers characterizing and identifying electrohypersensitivity and multiple chemical sensitivity as two etiopathogenic aspects of a unique pathological disorder. Rev. Environ. Health 30, 251–271.

Belyaev, I.Y., 2010. Dependence of non-thermal biological effects of microwaves on physical and biological variables: implications for reproducibility and safety standards. Eur J Oncol Library 5, 187–218.

Belyaev, I., 2015. Biophysical mechanisms for nonthermal microwave effects. In: Markov, M. (Ed.), Electromagnetic Fields in Biology and Medicine, vol. 2015. CRC Press, Boca Raton, London, New York, pp. 49–68.

Belyaev, I., 2017. Duration of exposure and dose in assessing nonthermal biological effects of microwaves. In: Dosimetry in Bioelectromagnetics. CRC Press, pp. 171–184.

Belyaev, I.Y., Alipov, Y.D., Harms-Ringdahl, M., 1997. Effects of zero magnetic field on the conformation of chromatin in human cells. Biochim. Biophys. Acta 1336, 465–473.

Belyaev, I.Y., Alipov, Y.D., Harms-Ringdahl, M., 1999. Effects of weak ELF on E. coli cells and human lymphocytes: role of genetic, physiological, and physical parameters. In: Bersani, F. (Ed.), Electricity and Magnetism in Biology and Medicine. Kluwer Academic/Plenum Publ, New York, pp. 481–484.

Belyaev, I., Dean, A., Eger, H., Hubmann, G., Jandrisovits, R., Kern, M., et al., 2016. EUROPAEM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses. Rev. Environ. Health 31, 363–397.

Belyaev, I.Y., Koch, C.B., Terenius, O., Roxstrom-Lindquist, K., Malmgren, L.O., Sommer, W., et al., 2006. Exposure of rat brain to 915-MHz GSM microwaves induces changes in gene expression but not double stranded DNA breaks or effects on chromatin confirmation. Bioelectromagnetics 27, 295–306.

Belyaev, IYa, Kravchenko, V.G., 1994. Resonance effect of low-intensity millimeter waves on the chromatin conformational state of rat thymocytes. Z. Naturforsch. C Biosci. 49, 352–358.

Belyaev, I.Y., Markovà, E., Hillert, L., Malmgren, L.O., Persson, B.R., 2009. Microwaves from UMTS/GSM mobile phones induce long-lasting inhibition of 53BP1/gamma-H2AX DNA repair foci in human lymphocytes. Bioelectromagnetics 30, 129–141.

Belyaev, I.Y., Shcheglov, V.S., Alipov, Y.D., Polunin, V.A., 1996. Resonance effect of millimeter waves in the power range from 10(-19) to 3 x 10(-3) W/cm2 on *Escherichia coli* cells at different concentrations. Bioelectromagnetics 17, 312–321.

Belyaev, I.Y., Shcheglov, V.S., Alipov, Y.D., Radko, S.P., 1993. Regularities of separate and combined effects of circularly polarized millimeter waves on *E. coli* cells at different phases of culture growth. Bioelectrochem. Bioenerg. 31, 49–63.

Bergqvist, U., Vogel, E., Authors, 1997. Possible health implications of subjective symptoms and electromagnetic fields. In: A Report Prepared by a European Group of Experts for the European Commission, DGV. Arbete Och Hälsa, 19. Swedish National Institute for Working Life, Stockholm, Sweden. Available from: http://www2.niwl.se/forlag/en/.

Beyer, C., Christen, P., Jelesarov, I., Fröhlich, J., 2013. Experimental system for real-time assessment of potential changes in protein conformation induced by electromagnetic fields. Bioelectromagnetics 34, 419–428.

Birks, L., Guxens, M., Papadopoulou, E., Alexander, J., Ballester, F., Estarlich, M., et al., 2017. Maternal cell phone use during pregnancy and child behavioral problems in five birth cohorts. Environ. Int. 104, 122–131.

Blackman, C., 2009. Cell phone radiation. Evidence from ELF and RF studies supporting more inclusive risk identification and assessment. Pathophysiology 16, 205–216.

Blank, M., Goodman, R., 1999. Electromagnetic fields may act directly on DNA. J. Cell. Biochem. 75, 369–374.

Blank, M., Goodman, R., 2011a. Electromagnetic fields stress living cells. Pathophysiology 16, 71–78.

Blank, M., Goodman, R., 2011b. DNA is a fractal antenna in electromagnetic fields. Int. J. Radiat. Biol. 87, 409–415.

Bohr, H., Bohr, J., 2013. Microwave enhanced kinetics observed in ORD studies of a protein. Bioelectromagnetics 21, 68–72.

Burlaka, A., Tsybulin, O., Sidorik, E., Lukin, S., Polishuk, V., Tsehmistrenko, S., et al., 2013. Overproduction of free radical species in embryonal cells exposed to low

intensity radiofrequency radiation. Exp. Oncol. 35, 219–225.
Byun, Y.H., Ha, M., Kwon, H.J., Hong, Y.C., Leem, J.H., Salong, J., et al., 2017. Mobile phone use, blood lead levels, and attention deficit hyperactivity symptoms in children: a longitudinal study. PLoS One 8, e59742.
Byus, C.V., Karun, K., Pieper, S., Ady, W.R., 1988. Increased ornithine decarboxylase activity in cultured cells exposed to low energy modulated microwave fields and porbol ester tumor promoters. Canc. Res. 48, 4222–4226.
Cardis, E., Armstrong, B.K., Bowman, J.D., Giles, G.G., Hours, M., Krewski, D., et al., 2011. Risk of brain tumours in relation to estimated RF dose from mobile phones: results from five Interphone countries. Occup. Environ. Med. 68, 631–640.
Cardis, E., Deltour, I., Mann, S., Moissonnier, M., Taki, M., Varsier, N., et al., 2008. Distribution of RF energy emitted by mobile phones in anatomical structures of the brain. Phys. Med. Biol. 53, 2771–2783.
Carlberg, M., Hardell, L., 2014. Decreased survival of glioma patients with astrocytoma grade IV (glioblastoma multiforme) associated with long-term use of mobile and cordless phones. Int. J. Environ. Res. Publ. Health 11, 10790–10805.
Carlberg, M., Hardell, L., 2015. Pooled analysis of Swedish case-control studies during 1997-2003 and 2007-2009 on meningioma risk associated with the use of mobile and cordless phones. Oncol. Rep. 33, 3093–3098.
Carlberg, M., Hardell, L., 2017. Evaluation of mobile phone and cordless phone use and glioma risk using the Bradford Hill viewpoints from 1965 on association or causation. BioMed Res. Int. 2017, 9218486. https://doi.org/10.1155/2017/9218486.
Carpenter, D.O., 2006. Environmental contaminants and learning and memory. Int. Congr. 1287, 185–189.
Carpenter, D.O., 2015. The microwave syndrome or electro-hypersensitivity: historical background. Rev. Environ. Health 30, 217–222.
Carter, B., Rees, P., Hale, L., Bhattacharjee, D., Paradkar, M.S., 2016. Association between portable screen-based media device access or use and sleep outcomes: a systematic review and meta-analysis. JAMA Pediatr 170, 1202–1208.
Cea-Soriano, L., Wallander, M.A., García Rodríguez, L.A., 2012. Epidemiology of meningioma in the United Kingdom. Neuroepidemiology 39, 27–34.
Choi, K.H., Ha, M., Ha, E.H., Park, H., Kim, Y., Hong, Y.C., et al., 2017. Neurodevelopment for the first three years following prenatal mobile phone use, radiofrequent radiation and lead exposure. Environ. Res. 156, 810–817.
Choi, S.B., Kwon, M.K., Chung, J.W., Park, J.S., Chung, K., Kim, D.W., 2014. Effects of short-term radiation emitted by WCDMA mobile phones on teenagers and adults. BMC Publ. Health 14, 438.
Chrousos, G.P., Gold, P.W., 1992. The concepts of stress and stress system disorders. Overview of physical and behavioral homeostasis. JAMA 267, 1244–1252.
Coureau, G., Bouvier, G., Lebailly, P., Fabbro-Peray, P., Gruber, A., Leffondre, K., et al., 2014. Mobile phone use and brain tumours in the CERENAT case-control study. Occup. Environ. Med. 71, 514–522.
Cucurachi, S., Tamis, W.L., Vijver, M.G., Peijnenburg, W.J., Bolte, J.F., de Snoo, G.R., 2013. A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF). Environ. Int. 51, 116–140.
Dasdag, S., Akdag, M.Z., Kizil, G., Kizil, M., Cakir, D.U., Yokus, B., 2012. Effect of 900 MHz radio frequency radiation on beta amyloid protein, protein carbonyl, and malondialdehyde in the brain. Electromagn. Biol. Med. 31, 67–74.
Dasdag, S., Akdag, M.Z., Erdal, M.E., Erdal, N., Av, O.L., Ay, M.E., et al., 2015. Effects of 2.4 GHz radiofrequency radiation emitted from Wi-Fi equipment on microRNA expression in brain tissue. Int. J. Radiat. Biol. 91, 555–561.
Davanipour, Z., Sobel, E., 2009. Long-term exposure to magnetic fields and the risks of Alzheimer's Disease and breast cancer. Pathophysiology 16, 149–156.
De Luca, C., Thai, J.C., Raskovic, D., Cesareo, E., Caccamo, D., Trukhanov, A., et al., 2014. Metabolic and genetic screening of electromagnetic hypersensitive subjects as a feasible tool for diagnostics and intervention. Mediat. Inflamm. 2014, 924184.
Deshmukh, P.S., Megha, K., Banerjee, B.D., Ahmed, R.S., Chandna, S., Abegaonkar, M.P., Tripathi, A.K., 2013. Detection of low level microwave radiation induced deoxyribonucleic acid damage vis-a-vis genotoxicity in brain of fischer rats. Toxicol. Int. 20, 19–24.
Deshmukh, P.S., Nasare, N., Megha, K., Banerjee, B.D., Ahmed, R.S., Singh, D., et al., 2015. Cognitive impairment and neurogenotoxic effects in rats exposed to low-intensity microwave radiation. Int. J. Toxicol. 34, 284–290.
Diem, E., Schwarz, C., Adlkofer, F., Jahn, O., Rüdiger, H., 2005. Non-thermal DNA breakage by mobile-phone radiation (1800 MHz) in human fibroblasts and in transformed GFSH-R17 rat granulosa cells in vitro. Mutat. Res. 583, 178–183.
Dieudonné, M., 2016. Does electromagnetic hypersensitivity originate from nocebo responses? Indications from a qualitative study. Bioelectromagnetics 37, 14–24.
Divan, H.A., Kheifets, L., Obel, C., Olsen, J., 2008. Prenatal and postnatal exposure to cell phone use and behavioral problems in children. Epidemiology 19, 523–529.
Divan, H.A., Kheifets, L., Obel, C., Olsen, J., 2012. Cell phone use and behavioural problems in young children. J. Epidemiol. Community Health 66, 524–529.
Dobes, M., Khurana, V.G., Shadbolt, B., Jain, S., Smith, S.F., Smee, R., et al., 2011. Increasing incidence of glioblastoma multiforme and meningioma, and decreasing incidence of Schwannoma (2000-2008): findings of a multicentre Australian study. Surg. Neurol. Int. 2, 176.
Dodge, C.H., 1970. Clinical and hygienic aspects of exposure to electromagnetic fields. In: Cleary, S.I. (Ed.), Biol. Effects and Health Implications of Microwave Radiation, "Symp. Proc, vols. 70–72, pp. 140–149. USDHEW, Dept. BRH/DBE.
Duan, Y., Zhang, Z., Bu, R.F., 2011. Correlation between cellular phone use and epithelial parotid gland malignancies. Int. J. Oral Maxillofac. Surg. https://doi.org/10.1016/j.ijom.2011.03.007.
Eberhardt, J.L., Persson, B.R.R., Brun, A.E., Salfor, L.G., Malmgren, L.O.G., 2008. Blood-brain barrier permeability and nerve cell damage in rat brain 14 and 28 days after exposure to microwaves for GSM mobile phones. Electromagn. Biol. Med. 27, 215–229.
Eghlidospour, M., Ghanbari, A., Mortazavi, S.M.J., Azari, H., 2017. Effects of radiofrequency exposure emitted from a GSM mobile phone on proliferation, differentiation, and apoptosis of neural stem cells. Anat Cell Biol 50, 115–123.
Eltiti, S., Wallace, D., Russo, R., Fox, E., 2015. Aggregated data from two double-blind base station provocation studies comparing individuals with idiopathic environmental intolerance with attribution to electromagnetic fields and controls. Bioelectromagnetics 36, 96–107.
Esmekaya, M.A., Ozer, C., Seyhan, N., 2011. 900 MHz pulse-modulated radiofrequency radiation induces oxidative stress on heart, lung, testis and liver tissues. Gen. Physiol. Biophys. 30, 84–89.
Etxeberrua, H., San Roman, E., Burgul, R., Guevara, M., Moreno-Iribas, C., Urbina, M.J., Ardanaz, E., 2015. Brain and central nervous system cancer incidence in Navarre (Spain), 1973-2008 and projections for 2014. J. Canc. 6, 177–183.
Falcioni, L., Bua, L., Tibaldi, M., Lauriola, L., De Angelis, F., Gnudi, F., et al., 2018. Report of final results regarding brain and heart tumors in Sparague-Dawley rats exposed from prenatal life until natural death to mobile phone radiofrequency field representative of a 1.8 GHz GSM base station. Environ. Res. 65, 496–503.
Falone, S., Grossi, M.R., Cinque, B., D'Angelo, B., Tettamanti, E., Cimini, A., et al., 2007. Fifty hertz extremely low-frequency electromagnetic field causes changes in redox and differentiative status in neuroblastoma cells. Int. J. Biochem. Cell Biol. 39, 2093–2106.
Fojt, L., Strasák, L., Vetterl, V., Smarda, J., 2004. Comparison of the low-frequency magnetic field effects on bacteria *Escherichia coli, Leclercia adecarboxylata* and *Staphylococcus aureus*. Bioelectrochemistry 63, 337–341.
Fragopoulou, A.F., Samara, A., Antonelou, M.H., Xanthopoulou, A., Papadopoulou, A., Vougas, K., et al., 2011. Brain proteome response following whole body exposure of mice to mobile phone or wireless DECT base radiation. Electromagn. Biol. Med. 31, 250–274.
Frey, A.H., 1993. Electromagnetic field interactions with biological systems. FASEB J 7, 272–281.
Friedman, J.1, Kraus, S., Hauptman, Y., Schiff, Y., Seger, R., 2007. Mechanism of short-term ERK activation by electromagnetic fields at mobile phone frequencies. Biochem. J. 405, 559–568.
Furtado-Filho, O.V., Borba, J.B., Maraschin, T., Souza, L.M., Henriques, J.A., Moreira, J.C., Saffi, J., 2015. Effects of chronic exposure to 950 MHz ultra-high-frequency electromagnetic radiation on reactive oxygen species metabolism in the right and left cerebral cortex of young rats of different ages. Int. J. Radiat. Biol. 91, 891–897.
Gandhi, O.P., Lazzi, G., Furse, C.M., 1996. Electromagnetic absorption in the human head and neck for mobile telephones at 835 and 1900 MHz. IEEE Trans. Microw. Theor. Tech. 44 (10), 1884–1897.
Gandhi, O.P., Morgan, L.L., de Salles, A.A., Han, Y.Y., Herberman, R.F., Davis, D.L., 2012. Exposure limits: the underestimation of absorbed cell phone radiation, especially in children. Electromagn. Biol. Med. 31, 34–51.
Gapeev, A.B., Iakushina, V.S., Chemeris, N.K., Fesenko, E.E., 1999a. Modulated extremely high frequency electromagnetic radiation of low intensity activates or inhibits respiratory burst in neutrophils depending on modulation frequency (in Russian). Biofizika 42, 1125–1134.
Gapeev, A.B., Iakushina, V.S., Chemeris, N.K., Fesenko, E.E., 1999b. Dependence of EHF EMF effects on the value of the static magnetic field. Dokl. Akad. Nauk. 369, 404–407.
García, A.M., Sisternas, A., Hoyos, S.P., 2008. Occupational exposure to extremely low frequency electric and magnetic fields and Alzheimer disease: a meta-analysis. Int. J. Epidemiol. 37, 329–340.
Geoffroy-Siraudin, C., Loundou, A.D., Romain, F., Achard, V., Courbiere, B., Perrad, M.H., et al., 2012. Decline of semen quality among 10932 males consulting for couple infertility over a 20-year period in Marseille, France. Asian J Andol 14, 584–490.
Goodman, R., Lin-Ye, A., Geddis, M.S., Wickramaratne, P.J., Hodge, S.E., Pantazatos, S.P., et al., 2009. Extremely low frequency electromagnetic fields activate the ERK cascade, increase hsp70 protein levels and promote regeneration in Planaria. Int. J. Radiat. Biol. 85, 851–859.
Grasso, C.M., D'Ascenzo, M., Torsello, A., Martinotti, G., Wolf, F., Cittadini, A., et al., 2004. Effects of 50 Hz electromagnetic fields on voltage-gated Ca^{2+} channels and their role in modulation of neuroendocrine cell proliferation and death. Cell Calcium 35, 307–315.
Greenland, S., Sheppard, A.R., Kaune, W.T., Poole, C., Kelsh MA for the Childhood Leukemia-EMF Study Group, 2000. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Epidemiology 11, 624–634.
Grell, K., Frederiksen, K., Schüz, J., Cardis, E., Armstrong, B., Siemiatycki, J., et al., 2016. The intracranial distribution of gliomas in relation to exposure from mobile phones: analyses from the INTERPHONE study. Am. J. Epidemiol. 184, 818–828.
Grigoriev, Y.G., Grigoriev, O.A., Ivanov, A.A., Lyaginskaya, A.M., Merkulov, A.V., Stepanov, V.S., et al., 2010. Autoimmune process after long-term low-level exposure to electromagnetic field (experimental results). Part 1. Mobile communications and changes in electromagnetic conditions for the population: need for additional substantiation of existing hygienic standards. Biophysics 55, 1041–1045.

Ha, M., Im, H., Lee, M., Kim, H.J., Kim, B.-C., Kim, B.-C., Gimm, Y.-M., Pack, J.-K., 2007. Radio-frequency radiation exposure from AM radio transmitters and childhood leukemia and brain cancer. Am. J. Epidemiol. 168, 270–279.
Hallberg, O., Oberfeld, G., 2006. Letter to the editor: will we all become electrosensitive? Electromagn. Biol. Med. 25, 189–191.
Hardell, L., 2017. World Health Organization, radiofrequency radiation and health – a hard nut to crack (Review). Int. J. Oncol. 51, 405–413.
Hardell, L., Carlberg, M., Söderqvist, F., Hansson Mild, K., 2013. Pooled analysis of case-control studies on acoustic neuroma diagnosed 1997-2003 and 2007-2009 and use of mobile and cordless phones. Int. J. Oncol. 43, 1036–1044.
Hardell, L., Carlberg, M., 2014. Long-term mobile phone use and acoustic neuroma. Epidemiology 25, 778.
Hardell, L., Carlberg, M., 2015. Mobile phone and cordless phone use and the risk for glioma – analysis of pooled case-control studies in Sweden, 1997-2003 and 2007-2009. Pathophysiology 22, 1–13.
Hardell, L., Carlberg, M., 2017. Mobile phones, cordless phones and rates of brain tumors in different age groups in the Swedish National Inpatient Register and the Swedish Cancer Register during 1998-2015. PLoS One 12 (10) e0185461. https://doi.org/10.1371/journal.pone.0185461.
Hardell, L., Näsman, Å., Påhlson, A., Hallquist, A., Hansson Mild, K., 1990. Use of cellular telephones and the risk for brain tumours: a case-control study. Int. J. Oncol. 15, 113–116.
Hansson Mild, K., Repacholi, M., van Deventer, E., Ravazzani, P. (Eds.), 2006. Electromagnetic Hypersensitivity: Proceedings, International Workshop on EMF Hypersensitivity, Prague, Czech Republic, October 25-27, 2004. Geneva (Switzerland). WHO Press, p. 16.
Havas, M., 2013. Radiation from wireless technology affects the blood, the heart, and the autonomic nervous system. Rev. Environ. Health 28, 75–84.
Hedendahl, L., Carlberg, M., Hardell, L., 2015. Electromagnetic hypersensitivity - an increasing challenge to the medical profession. Rev. Environ. Health 30, 209–215.
Heuser, G., Heuser, S.A., 2017. Functional brain MRI in patients complaining of electrohypersensitivity after long term exposure to electromagnetic fields. Rev. Environ. Health 32, 291–299.
Ho, V.K.Y., Reijneveld, J.C., Enting RHBienfait, H.P., Robe, P., Baumert, B.G., Visser, O., on behalf of the Dutch Society of Neuro-Oncology, 2014. Changing incidence and improved survival of gliomas. Eur. J. Canc. 50, 2309–2318.
Holmstrom, K.M., Finkel, T., 2014. Cellular mechanisms and physiological consequences of redox-dependent signaling. Nat. Rev. Mol. Cell Biol. 15, 411–421.
Huang, P.C., Cheng, M.T., Guo, H.R., 2018. Representative survey on idiopathic environmental intolerance attributed to electromagnetic fields in Taiwan and comparison with the international literature. Environ. Health 17, 5–12.
Huber, R., Treyer, V., Schuderer, J., Berthold, T., Buck, A., Kuster, N., et al., 2005. Exposure to pulse-modulated radio frequency electromagnetic fields affects regional cerebral blood flow. Eur. J. Neurosci. 21, 1000–1006.
Huber, R., Treyer, V., Borbély, A.A., Schuderer, J., Gottselig, J.M., Landolt, H.P., et al., 2002. Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG. J. Sleep Res. 11, 289–295.
Huss, A., Peters, S., Vermeulen, R., 2018. Occupational exposure to extremely low-frequency magnetic fields and the risk of ALS: a systematic review and meta-analysis. Bioelectromagnetics 39, 156–163.
IARC (International Agency for Research on Cancer), 2002. IARC monographs on the evaluation of carcinogenic risks to humans. In: Non-ioizing Radiation, Part 1: Static and Extremely Low-frequency (ELF) Electric and Magnetic Fields, vol. 80. IARC Press, Lyon, France, 341pp.
IARC (International Agency for Research on Cancer), 2013. IARC monographs on the evaluation of carcinogenic risks to humans. In: Non-ionization Radiation, Part 2: Radiofrequency Electromagnetic Fields, vol. 102. IARC Press, Lyon, France, 406 pp.
IEG (Independent Expert Group on Mobile Phones), 2000. Report of the Group (The Stewart Report). Available at: www.iegmp.org.uk/report/index.htm.
Interphone Study Group, 2011. Acoustic neuroma risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. Cancer Epidemiol 35, 453–464.
Interphone Study Group, 2010. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. Int. J. Epidemiol. 39, 675–694.
Irigaray, P., Caccamo, D., Belpomme, D., 2018b. Oxidative stress in electrohypersensitivity self-reporting patients: results of a prospective in vivo investigation with comprehensive molecular analysis. Int. J. Mol. Med. https://doi.org/10.3892/ijmm.
Irigaray, P., Garrel, C., Houssay, C., Mantello, P., Belpomme, D., 2018a. Beneficial effects of a fermented papaya preparation for the treatment of electrohypersensitivity self-reporting patients: results of a phase I-II clinical trial with special reference to cerebral pulsation measurement and oxidative stress analysis. Funct Foods Health Dis 8, 122–144.
Irigaray, P., Lebar, P., Belpomme, D., 2018c. How ultrasonic cerebral tomosphygmography can contribute to the diagnosis of electrohypersensitivity. JBR J. Clin. Diag. Res. In press.
ISD (International Scientific Declaration on EHS & MCS), 2015. Brussels International Scientific Declaration on Electromagnetic Hypersensitivity and Multiple Chemical Sensitivity Following the 5th Paris Appeal Congress that Took Place on the 18th of May, 2015 at the Royal Academy of Medicine, Brussels, Belgium. Available from: http://eceri-institute.org/fichiers/1441982737_Statment_FR_DEFINITIF.pdf.
Jaffe, L.F., Nuccitelli, R., 1977. Electrical controls of development. Annu. Rev. Biophys. Bioeng. 6, 445–213.
Jakovljevic, M., 2014. The placebo-nocebo response: controversies and challenges from clinical and research perspective. Eur. Neuropsychopharmacol 24, 333–341.
Ji, Y., He Q,Sun, Y., Tong, J., Cao, Y., 2016. Adaptive respone in mouse bone-marrow stromal cells exposed to 900-MHz radiofrequency fields: gamma-radiation-induce DNA strand breaks and repair. J. Toxicol. Environ. Health 79, 419–426.
Johansen, C., Boice Jr., J., McLaughlin, J., Olsen, J., 2001. Cellular telephones and cancer – a nationwide cohort study in Denmark. J. Natl. Cancer Inst. 93, 203–207.
Johansson, A., Nordin, S., Heiden, M., Sandström, M., 2010. Symptoms, personality traits, and stress in people with mobile phone-related symptoms and electromagnetic hypersensitivity. J. Psychosom. Res. 68, 37–45.
Juutilainen, J., Matilainen, P., Saankoski, S., Laara, E., Suonio, S., 1993. Early pregnancy loss and exposure to 50-Hz magnetic fields. Bioelectromagnetics 14, 229–236.
Kabali, H.K., Irigoyen, M.M., Nunez-Davis, R., Budacki, J.G., Mohanty, S.H., Leister, K.P., Bonner Jr., R.L., 2015. Exposure and use of mobile media devices by young children. Pediatrics 136, 1044–1050.
Kesari, K.K., Kumar, S., Behari, J., 2011. 900-MHz microwave radiation promotes oxidation in rat brain. Electromagn. Biol. Med. 30, 219–234.
Kesari, K.K., Meena, R., Nirala, J., Kumaar, J., Verma, H.N., 2014. Effect of 3G cell phone exposure with computer controlled 2-D stepper motor on non-thermal activation of the hsp27/p38MAPK stress pathway in rat brain. Cell Biochem. Biophys. 68, 347–358.
Kheifets, L., Repacholi, M., Saunders, R., van Deventer, E., 2005. The sensitivity of children to electromagnetic fields. Pediatrics 116, e303–e313.
Koivisto, M., Revonsuo, A., Krause, C., Laarala, C., Sillanmaki, L., et al., 2000. Effects of 902 MHz electromagnetic filed emitted by cellular telephones on response times in humans. Cog Neurosci Neuropsychol 11, 413–415.
Koyu, A., Cesur, G., Ozguner, F., Akdogan, M., Mollaoglu, H., Ozen, S., 2005. Effects of 900 MHz electromagnetic field on TSH and thyroid hormones in rats. Toxicol. Lett. 137, 257–262.
Kumari, K., Kolviato, H., Viluksela, M., Paidanius, K.M.A., Maritinen, M., Hilitunen, M., et al., 2017. Behavioral testing of mice exposed to intermediate frequency magnetic fields indicates mild memory impairment. PLoS One 12, e188880.
Lai, H., Singh, N.P., 1997. Melatonin and a spin-trap compound block radiofrequency electromagnetic radiation-induced DNA strand breaks in rat brain cells. Bioelectromagnetics 18, 446–454.
Lai, H., Singh, N., 2004. Magnetic field-induced DNA strand breaks in brain cells of the rat. Environ. Health Perspect. 112, 687–694.
Ledoigt, G., Belpomme, D., 2013. Cancer induction molecular pathways and HF-EMF irradiation. Adv. Biol. Chem. 3, 177–186.
Lee, T.M.C., Ho, S.M.Y., Tsang, L.Y.H., Yang, S.Y.C., Li, L.S.W., Chan, C.C.H., 2001. Effect on human attention of exposure to the electromagnetic field emitted by mobile phones. Cog Neurosci Neuropsychol 12, 729–731.
Lenhart, A., 2015. Teens, social media & technology overview. Pew Research Center, 47 pages. Retrived from. http://pewinternet.org/2015/04/09/teens-social-media-technology.2015.
Leone, L., Fusco, S., Mastrodonato, A., Piacentini, R., Barbati, S.A., et al., 2014. Epigenetic modulation of adult hippocampal neurogenesis by extremely low-frequency electromagnetic fields. Mol. Neurobiol. 49, 1472–1486.
Lerchl, A., Klose, M., Grote, K., Wilhelm, A.F., Spathmann, O., Fiedler, T., et al., 2015. Tumor promotion by exposure to radiofrequency electromagnetic fields below exposure limits for humans. Biochem. Biophys. Res. Commun. 459, 585–590.
Levin, M., 2003. Bioelectromagnetics in morphogenesis. Bioelectromagnetics 24, 295–315.
Levine, H., Jorgensen, N., Martino-Andrade, A., Mendiola, J., Weksler-Derri, D., Mindlis, I., et al., 2017. Temporal trends in sperm count: a systematic review and meta-regression analysis. Hum. Reprod. Update 23, 646–659.
Li, D.K., Chen, H., Ferber, J.R., Odouli, R., Quesenberry, C., 2017. Exposure to magnetic field non-ionizing radiation and the risk of miscarriage: a prospective cohort study. Sci. Rep. 7, 17541.
Liburdy, R.P., Vanek Jr., P.F., 1987. Microwaves and the cell membrane. III. Protein shedding is oxygen and temperature dependent: evidence for cation bridge involvement. Radiat. Res. 109, 382–395.
Lin, H., Blank, M., Goodman, R., 1999. A magnetic field-responsive domain in the human HSP70 promoter. J. Cell. Biochem. 75, 170–176.
Lin, H., Blank, M., Rossol-Haseroth, K., Goodman, R., 2001. Regulating genes with electromagnetic response elements. J. Cell. Biochem. 81, 143–148.
Luo, Q., Jiang, Y., Jin, M., Xu, J., Huang, H.F., 2013. Proteomic anlaysis on the alteration of protein expression in the early-stage placental villous tissue of electromagnetic fields associated with cell phone exposure. Reprod. Sci. 20, 1055–1061.
Lyle, D.B., Schecher, P., Adey, W.R., Lundak, R.L., 1983. Suppression of T-lymphocyte cytotoxicity following exposure to sinusoidally ampltudee-modulated fields. Bioelectromagnetics 4, 281–292.
Ma, Q., Deng, P., Zhu, G., Liu, C., Zhang, L., Zhou, Z., et al., 2014. Extremely low-frequency electromagnetic fields affect transcript levels of neuronal differentiation-related genes in embryonic neural stem cells. PLoS One 9, e90041.
Maffei, M.E., 2014. Magnetic field effects on plant growth, development, and evolution. Front. Plant Sci. 5, 445. https://doi.org/10.3389/fpls.2014.00445.
Mahmoudabadi, F.S., Ziaei, S., Firoozabadi, M., Kazemnejad, A., 2015. Use of mobile

phone during pregnancy and the risk of spontaneous abortion. J Environ Health Sci Eng 13, 34. https://doi.org/10.1186/s40201-015-0193-z.
Maisch, D., 2006. Conflict of interest & bias in health advisory committees: a case study of the WHO's Electromgagnetic Field (EMF) Task Group. J Aust Coll Nutr & Env Med 25, 15–17.
Markov, M., Grigoriev, Y., 2015. Protect children from EMF. Electromagn. Biol. Med. 34, 251–256.
Markova, E., Hillert, L., Malmgren, L., Persson, B.R., Belyaev, Y., 2005. Microwaves from GSM mobile telephones affect 53BP1 and gamma-H2AZ foci in human lymphocytes from hypersensitive and healthy persons. Environ. Health Perspect. 113, 1172–1176.
Markova, E., Malmgren, L., Belyaev, I., 2010. Microwaves from mobile phones inhibit 53BP1 focus formation in human stem cells stronger than in differentiated cells: possible mechanistic link to cancer risk. Environ. Health Perspect. 118, 394–399.
Mashevich, M., 2003. Exposure of human peripheral blood lymphocytes to electromagnetic fields associated with cellular phones leads to chromosomal instability. Bioelectromagnetics 24, 82–90.
McCarty, D.E., Carrubba, S., Chesson, A.L., Frilot, C., Gonzalez-Toledo, E., Marino, A.A., 2011. Electromagnetic hypersensitivity: evidence for a novel neurological syndrome. Int. J. Neurosci. 121, 670–676.
McGill, J.J., Agarwal, A., 2014. The impact of cell phone, laptop computer, and microwave oven usage on male fertility. In: du Plessis al, S.S. (Ed.), Male Infertility: a Complete Gide to Lifestydl Ad Environmental Factors. Springer Sciece + buxiness Media, New York. https://doi.org/10.1007/978-1-4939-1040-3_11.
Medeiros, L.N., Sanchez, T.G., 2016. Tinnitus and cell phones: the role of electromagnetic radiofrequency radiation. Braz J Otorhinolaryngol 82, 97–104.
Megha, K., Deshmukh, P.S., Banerjee, B.D., Tripathi, A.K., Ahmed, R., Abegaonkar, M.P., 2015. Low intensity microwave radiation induced oxidative stress, inflammatory response and DNA damage in rat brain. Neurotoxicology 51, 158–165.
Michelozzi, P., Capon, A., Kirchmayer, U., Forastiere, F., Biggeri, A., Barca, A., Perucci, C.A., 2002. Adult and childhood leukemia near a high-power radio station in Rome. Am. J. Epidemiol. 155, 1096–1103.
Momoli, F., Siemiatycki, J., McBride, M.L., Parent, M.E., Richardson, L., Bedard, D., Platt, R., et al., 2017. Probabilistic multiple-bias modelling applied to the Canadian data from the INTERPHONE study of mobile phone use and risk of glioma, meningioma, acoustic neuroma, and parotid gland tumors. Am. J. Epidemiol. 186, 885–893.
Moon, I.S., Kim, B.G., Kim, J., Lee, J.D., Lee, W.S., 2014. Association between vestibular schwannomas and mobile phone use. Tumour Biol. 35, 581–587.
Mortavazi, S., Habib, A., Ganj-Karami, A., Samimi-Doost, R., Pour-Abedi, A., Babaie, A., 2009. Alterations in TSH and thyroid hormones following mobile phone use. Oman Med. J. 24, 274–278.
Mousavy, S.J., Riazi, G.H., Kamarel, M., Aliakbarian, H., Sattarahmady, N., Sharifizadeh, A., et al., 2009. Effects of mobile phone radiofrequency on the structure and function of normal human haemoglobin. Int. J. Biol. Macromol. 44, 278–285.
Muehsam, D., Lalezari, P., Lekhraj, R., Abruzzo, P., Boiotta, A., Marini, M., et al., 2013. Non-thermal radio frequency and static magnetic fields increase rate of haemoglobin deoxygenation in a cell-free preparation. PLoS One 8, e61752.
Nazıroğlu, M., Yüksel, M., Köse, S.A., Özkaya, M.O., 2013. Recent reports of Wi-Fi and mobile phone-induced radiation on oxidative stress and reproductive signaling pathways in females and males. J. Membr. Biol. 246, 869–875.
Needleman, H.L., Gunnoe, C.G., Leviton, A., Reed, R.R., Peresie, H., Maher, C., Barrett, P., 1979. Deficits in psychologic and classroom performance of children with elevated dentine lead levels. N. Engl. J. Med. 300, 684–695.
Nordal, R.A., Wong, C.S., 2005. Molecular targets in radiation-induced blood-brain barrier disruption. Int. J. Radiat. Oncol. Biol. Phys. 62, 279–287.
Nordenson, I., Mild, K.H., Andersson, G., Sandström, M., 1994. Chromosomal aberrations in human amniotic cells after intermittent exposure to fifty hertz magnetic fields. Bioelectromagnetics 15, 293–301.
Nordin, S., Neely, G., Olsson, D., Sandström, M., 2014. Odor and noise intolerance in persons with self-reported electromagnetic hypersensitivity. Int. J. Environ. Res. Publ. Health 11, 8794–8805.
Novoselova, E.G., Glushkova, O.V., Khrenov, M.O., Novoselova, T.V., Lunin, S.M., et al., 2017. Extremely low-level microwaves attenuate immune imbalance induced by inhalation exposure to low-level toluene in mice. Int. J. Radiat. Biol. 93, 535–543.
Odaci, E., Hanci, H., Okinci, A., Fikret, O., Sonmez, F., Aslan, A., et al., 2016. Maternal exposure to a continuous 900-MHz electromagnetic field provokes neuronal loss and pathological changes in cerebellum of 32-day female rat offspring. J Clin Neuroanat 75, 105–110.
Ohgaki, H., Kleihues, P., 2005. Population-based studies on incidence, survival rates, and genetic alterations in astocytic and oligodendroglial gliomas. J. Neuropathol. Exp. Neurol. 64, 479–489.
Oscar, K.J., Hawkins, T.D., 1977. Microwave alteration of the blood-brain barrier system of rats. Brain Res. 126, 281–293.
Ostrom, Q.T., Gittleman, H., Fulo0, J., Liu, M., Blanda, R., Kromer, C., et al., 2015. CBTRUS statistical report: primary brain and central nervous system tumors diagnosed in the United States in 2008-2012. Neuro Oncol. 17, iv1–iv62.
Panagopoulos, D.J., Johansson, O., Carlo, G.L., 2015. Real versus simulated mobile phone exposures in experimental studies. BioMed Res. Int., 607053
Parini, M., Lepetit, J.M., Dumas, M., Tapie, P., Lemoine, J., 1984. Ultrasonic cerebral tomosphygmography. Application in 143 healthy subjects. Agressologie 25, 585–589.
Park, J.E., Seo, Y.K., Yoon, H.H., Kim, C.W., Park, J.K., Jeon, S., 2014. Electromagnetic fields induce neural differentiation of human bone marrow derived mesenchymal stem cells via ROS mediated EGFR activation. Neurochem. Int. 62, 418–424.
Pawlak, K., Seehman, B., Nieckarz, Z., 2014. Plasma thyroid hormones and corticosterone levels in blood of chicken embryos and post-hatch chickens exposed during incubation to 1800 MHz electromagnetic fields. Int. J. Occup. Med. Environ. Health 27, 114–122.
Paz de la Puente, M., Balmori, A., 2007. Addiction to cell phones: are there neurophysiological mechanisms involved? Proyecto 61, 8–12 s. 8.
Persson, B.R.R., Salford, L.G., Brun, A., 1997. Blood-brain barrier permeability in rats exposed to electromagnetic fields used in wireless communication. Wireless Network 3, 455–461.
Pettersson, D., Mathiesen, T., Prochazka, M., Bergenheim, T., Florentzson, R., Harder, H., et al., 2014. Long-term mobile phone use and acoustic neuroma risk. Epidemiology 25, 233–241.
Philips, A., Henshaw, D.L., Lamburn, G., O'Carroll, M.J., 2018. Brain tumours: rise in glioblastoma multiforme incidence in England 1995-2015 suggests an adverse environmental or lifestyle factor. J Environ Public Health, 7910754, 10 pages.
Purlauastja, S., Sorond, P., 2012. Transcranial Doppler ultrasound: technique and application. Semin. Neurol. 32, 411–420.
Qiu, C., Fratiglioni, L., Karp, A., Winblad, B., Bellander, T., 2004. Occupational exposure to electromagnetic fields and risk of Alzheimer's disease. Epidemiology 15, 687–694.
Rea, W.J., Pan, Y., Fenyves, E.F., Sujisawa, I., Suyama, H., et al., 1991. Electromaagnetic field sensitivity. J Bioeletricity 10, 214–256.
RNCNIRP (Russian National Committee on Non-Ionizing Radiation Protection), 2011. Resolution: Electromagnetic Fields from Mobile Phones: Health Effect on Children and Teenagers. 19th April 2011. Available at: http://iemfa.org/images/pdf/RNCNIRP_Resolution_2011.pdf.
Roberts, J.A., Yaya, L.H., Manolis, C., 2014. The invisible addiction: cell-phone activities and addiction among male and female college students. J Behav Addict 3, 254–265.
Rodrequez-De la Fuente, A.O., Alcocer-Gonzalez, J.M., Heredia-Rojas, J.A., Rodriquez-Padilla, C., Rodriquez-Flores, L.E., et al., 2010. Effect of 60 Hz electromagnetic fields on the activity of hsp70 promotoer: an *in vivo* study. Cell Biol. Int. Rep. 19 e00014.
Rolland, M., Le Moal, J., Wagner, V., Royere, D., De Mouzon, J., 2013. Decline in semen concentration and morphology in a sample of 26,609 men close to general population between 1989 and 2005 in Europe. Hum. Reprod. (Eynsham) 28, 462–270.
Röösli, M., 2008. Radiofrequency electromagnetic field exposure and non-specific symptoms of ill health: a systematic review. Environ. Res. 107, 277–287.
Roshangar, L., Hamdi, B.A., Khaki, A.A., Rad, J.S., Soleimani-Rad, S., 2014. Effect of low-frequency electromagnetic field exposure on oocyte differentiation and follicular development. Adv. Biomed. Res. 3, 76.
Roux, D., Vian, A., Girard, S., Bonnet, P., Paladian, F., Davies, E., et al., 2008. High frequency (900 MHz) low amplitude (5 V m-1) electromagnetic field: a genuine environmental stimulus that affects transcription, translation, calcium and energy charge in tomato. Planta 227, 883–891.
Rubin, G.J., Hillert, L., Nieto-Hernandez, R., van Rongen, E., Oftedal, G., 2011. Do people with idiopathic environmental intolerance attributed to electromagnetic fields display physiological effects when exposed to electromagnetic fields? A systematic review of provocation studies. Bioelectromagnetics 32, 593–609.
Sadetzki, S., Chetrit, A., Jarus-Hakak, A., Cardis, E., Deutch, Y., Duvdevani, Sh, et al., 2007. Cellular phone use and risk of benign and malignant parotid gland tumors – a nationwide case-control study. Am. J. Epidemiol. 167, 457–467.
Sage, C., Burgio, E., 2017. Electromagnetic fields, pulsed radiofrequency radiation, and epigenetics: how wireless technologies may affect childhood development. Child Dev. https://doi.org/10.1111/cdev.12824.
Saili, L., Hanini, A., Smirani, C., Azzouz, I., Azzouz, A., Sakly, M., et al., 2015. Effects of acute exposure to WiFi signals (2.45GHz) on heart variability and blood pressure in albino rabbits. Environ. Toxicol. Pharmacol. 40, 600–605.
Sannino, A., Zeni, O., Sarti, M., Romeo, S., Reddy, S.B., et al., 2011. Induction of adaptive response in human blood lymphocytes exposed to 900 MHz radiofrequency fields: influence of cell cycle. Int. J. Radiat. Biol. 87, 993–999.
Sannino, A., Zeni, O., Romeo, S., Massa, R., Gialanella, G., Grossi, G., Manti, L., Vijayalaxmi, Scarfi, M.R., 2014. Adaptive response in human blood lymphocytes exposed to non-ionizing radiofrequency fields: resistance to ionizing radiation-induced damage. J. Radiat. Res. 55, 210–217.
Santini, R., Seigne, M., Bonhomme-Faivre, L., Bouffet, S., Defrasme, E., Sage, M., 2001. Symptoms experienced by users of digital cellular phones: a study of a French engineering school. Electromagn. Biol. Med. 21, 81–88.
Santini, R., Santini, P., Le Ruz, P., Danze, J.M., Seigne, M., 2003. Survey study of people living in the vicinity of cellular phone base. Electromagn. Biol. Med. 22, 41–49.
Sato, Y., Akiba, S., Kubo, O., Yamaguchi, N., 2011. A case-case study of mobile phone use and acoustic neuroma risk in Japan. Bioelectromagnetics 32, 85–93.
SCENIHR (Scientific Committee on Emerging Newly Identified Health Risk), 2009. Health Effects of Exposure to EMF. European Commission. Directorate-General for Health & Consumers, 19 January 2009.
Schwartz, C., Kratochvil, E., Pilger, A., Kuster, N., Adlkofer, F., Rudiger, H.W., 2008. Radiofrequency electromagnetic fields (UMTS, 1,950 MHz) induce genotoxic effects *in vitro* in human fibroblasts but not in lymphocytes. Int. Arch. Occup.

Environ. Health 81, 755–767.
Schüz, J., Jacobsen, R., Olsen, J.H., Boice Jr., J.D., McLaughlin, J.K., et al., 2006. Cellular telephone use and cancer risk: update of a nationwide Danish cohort. J. Natl. Cancer Inst. 98, 1707–1713.
Semin, I.A., 1995. Changes in secondary structure of DNA under the influence of electromagnetic fields. Radiats Biol Radioecol 35, 36–41.
Shahin, S., Banerjee, S., Swarup, V., Singh, S.P., Chaturvedi, C.M., 2017. 2.45 GHz microwave radiation impairs hippocampal learning and spatial memory: involvement of local stress mechanism induced suppression of iGluR/ERK/CREB signaling. Toxicol. Sci. 161, 349–374.
Sirav, B., Seyhan, N., 2009. Blood-brain barrier disruption by continuous-wave radio frequency radiation. Electromagn. Biol. Med. 28, 213–222.
Sirav, B., Seyhan, N., 2016. Effects of GSM modulated radio-frequency electromagnetic radiation on permeability of blood-brain barrier in male & female rats. J. Chem. Neuroanat. 75, 123–127.
Sly, J.L., Carpenter, D.O., 2012. Special vulnerability of children to environmental exposures. Rev. Environ. Health 27, 151–157.
Smith-Roe, S.L., Wyde, M.E., Stout, M.D., Winters, J.W., Hobbs, C.A., Shepard, K.G., et al., 2017. Evaluation of the genotoxicity of cell phone radiofrequency radiation in male and female rats and mice following subchronic exposure. In: Environmental Mutagenesis and Genomics Society, Annual Meeting, Raleigh, North Carolina, USA September 9–13.
Sobel, E., Dunn, M., Davanipour, Z., Qian, Z., Chui, H.C., 1996. Elevated risk of Alzheimer's disease among workers with likely electromagnetic field exposure. Neurology 47, 1477–1481.
Söderqvist, F., Carlberg, M., Hardell, L., 2012a. Review of four publications on the Danish cohort study on mobile phone subscribers and risk of brain tumors. Rev. Environ. Health 27, 51–58.
Söderqvist, F., Carlberg, M., Hardell, L., 2012b. Use of wireless phones and risk of salivary gland tumours: a case-control study. Eur. J. Canc. Prev. 21, 576–579.
Sonmez, O.F., Odaci, E., Bas, O., Kaplan, S., 2010. Purkinje cell number decreases in the adult female rat cerebellum following exposure to 90 MHz electromagnetic fields. Brain Res. 1356, 95–101.
Spadaro, J.A., Bergstrom, W.H., 2002. In vivo and *in vitro* effects of a pulsed electromagnetic field on net calcium flux in rat clavarial bone. Calcif. Tissue Int. 70, 496–502.
Starkey, S.J., 2016. Inaccurate official assessment of radiofrequency safety by the Advisory Group on Non-ionizing radiation. Rev. Environ. Health 31, 493–501.
State of California, 2017. How to reduce exposure to radiofrequency energy from cell phones. In: Division of Environmental and Occupational Disease Control, California Department of Public Health, December, 2017.
Sun, Z.C., Ge, J.L., Guo, B., Guo, J., Hao, M., Wu, Y.C., et al., 2016. Extremely low frequency electromagnetic fields facilitate vesicle endocytosis by increasing presynaptic calcium channel expression at a central synapse. Sci. Rep. 6, 21774.
Tice, R.R., Hook, G.G., Donner, M., McRee, D.I., Guy, A.W., 2002. Genotoxicity of radiofrequency signals. 1. Investigation of DNA damage and micronuclei induction in cultured human blood cells. Bioelectromagnetics 23, 113–128.
Tillmann, T., Ernst, H., Streckert, J., Zhou, Y., Taugner, F., Hansen, V., et al., 2010. Indication of cocarcinogenic potential of chronic UMTS-modulated radiofrequency exposure in an ethylnitrosourea mouse model. Int. J. Radiat. Biol. 86, 529–541.
Vijayalaxmi, Pridoda, T.J., 2009. Genetic damage in mammalian somatic cells exposed to extremely low frequency electro-magnetic fields: a meta-analysis of data from 87 publications (1990-2007). Int. J. Radiat. Biol. 85, 196–213.
Vijayalaxmi, Reddy AB., McKenzie, R.J., McIntosh, R.L., Prihoda, T.J., Wood, A.W., 2013. Incidence of micronuclei in human peripheral blood lymphocytes exposed to modulated and unmodulated 2450 MHz radiofrequency fields. Bioelectromagnetics 34, 542–548.
Vojisavljevic, V., Pirogova, E., Cosic, I., 2010. Review of studies on modulating enzyme activity by low intensity electromagnetic radiation. Conf Proc IEEE Eng Med Biol Soc 835–838.
Volkow, N.D., Tomasi, D., Wang, G.F., Vaska, P., Fowler, J.S., Teland, F., et al., 2011. Effects of cell phone radiofrequency signal exposure on brain glucose metabolism. J. Am. Med. Assoc. 305, 808–814.
Wang, J., Su, H., Xie, W., Yu, S., 2017. Mobile phone use and the risk of headache: a systematic review and meta-analysis of cross-sectional studies. Sci. Rep. 7, 12595.
Wei, J., Sun, J., Xu, H., Shi, L., Sun, L., Zhang, J., 2015. Effects of extremely low frequency electromagnetic fields on intracellular calcium transients in cardiomyocytes. Electromagn. Biol. Med. 34, 77–84.
Wei, L.X., Goodman, R., Henderson, A., 1990. Changes in levels of c-myc and histone H2B following exposure of cells to low frequency sinusoidal electromagnetic fields: evidence for a window effect. Bioelectromagnetics 11, 269–272.
West, J.G., Kopoor, N.S., Liao, S.-Y., Chen, J.W., Bailey, L., Nagourney, R.A., 2013. Multifocal Breast Cancer in Young Women with Prolonged Contact between Their Breast and Their Cllular Phones. Case Report Med. https://doi.org/10.1155//2013/354682.
WHO (World Health Organization, 2005. WHO Fact Sheet No. 296. Electromagnetic Fields and Public Health, Electromagnetic Hypersensitivity. Available from: http://www.who.int/peh-emf/publications/facts/fs296/en/.
WHO (World Health Organization), 2014. Electromagnetic Fields and Public Health: Mobile Phones. Fact sheet No. 193, reviewed October, 2014.
Wolf, F.I., Torsello, A., Tedesco, B., Fasanella, S., Boninsegna, A., D'Ascenzo, M., et al., 2007. 50-Hz extremely low frequency electromagnetic fields enhance cell proliferation and DNA damage: possible involvement of a redox mechanism. Biochim. Biophys. Acta 1743, 120–129.
Wyde, M., Cesta, M., Blystone, C., Elmore, S., Foster, P., Hooth, M., et al., 2016. Report of Partial Findings from the National Toxicology Program Carcinogenesis Studies of Cell Phone Radiofrequency Radiation in Hsd: Sprague Dawley® SD Rats (Whole Body Exposures). Draft 5-19-2016. US National Toxicology Program (NTP). Available online: https://doi.org/10.1101/055699 http://biorxiv.org/content/biorxiv/early/2016/05/26/055699.full.pdf (accessed on 30 July, 2017).
Yan, H.G., Agresti, M., Zhang, L.L., Yan, Y., Mathoul, H.S., 2008. Upregulation of specific mRNA levels in rat brain after cell phone exposure. Electromagn. Biol. Med. 27, 147–154.
Yang, X.S., He, G.L., Hao, Y.T., Xiao, Y., Chen, C.H., Zhang, G.B., et al., 2012. Exposure to 2.45 GHz electromagnetic fields elicits an HSP-related stress response in rat hippocampus. Brain Res. Bull. 88, 371–278.
Yang, Y., Jin, X., Yn, C., Tian, Y., Tang, J., Shen, X., 2008. Case-only study of interactions between DNA repair genes (hMLH1, APEX1, MGMT, XRCC1 and XPD) and low-frequency electromagnetic fields in childhood acute leukemia. Leuk. Lymphoma 49, 2344–2350.
Zhang, X., Liu, X., Pan, L., Lee, I., 2010. Magnetic fields at extremely low-frequency (50 Hz, 0.8 mT) can induce the uptake of intracellular calcium levels in osteoblasts. Biochem. Biophys. Res. Commun. 396, 662–666.
Zhang, Y., Li, Z., Gao, Y., Zhang, C., 2015. Effects of fetal microwave radiation exposure on offspring behavior in mice. J. Radiat. Res. 56, 261–268.